BASE METAL MINERALISATION IN SAWAR-BAJTA BELT, DISTRICT AJMER, RAJASTHAN

ABSTRACT

THESIS
SUBMITTED FOR THE DEGREE OF
Doctor of Philosophy
IN
GEOLOGY

BY
MOHD. WAKEEL

DEPARTMENT OF GEOLOGY
ALIGARH MUSLIM UNIVERSITY
ALIGARH (INDIA)
1998


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ABSTRACT

The study area forms a part of Bhilwara Supergroup and has been named as Sawar Group of Ajmer district in Rajasthan, India.

The Sawar Group has been classified into the lower marble, lower schist, upper marble, upper schist and silicified quartzite.

Lower marble of the Sawar Group is the host rock for the sulphide mineralisation and it is composed of calcite, dolomite, muscovite, chlorite, biotite, sericite, apatite, feldspar and forsterite. Calcite upto two generation and quartz upto four generation has been recognised.

The general strike trend of the rocks of the area is from NNE to SSW whereas, at the fold closure the strike trend is in the East-West direction.

The deformation history of the area reveals that three distinct deformation stages effected the rocks of the area to a great extent and the structural pattern of the rocks are coaxial with the tectonic evolution of the area.

The host rocks have suffered alteration due to sericitization, argillization and silicification.

The petrographic studies of the minerals reveal that they have undergone progressive metramorphism upto amphibolite facies.

The sulphide ores are of mainly disseminated type and the ore minerals of the area identified are galena, sphalerite, chalcopyrite, pyrrhotite, pyrite, cubanite, marcasite, delafossite, goethite, cerrusite and cuprite.

The paragenetic sequence of the ore minerals has been determined.

The replacement, annealing and deformation texture indicate that the ores were subjected to dyanamothermal metamorphism whereas, the exsolution texture of the chalcopyrite with sphalerite in the form of sphalerite star, sphalerite with pyrrhotite and chalcopyrite with cubanite in the form of cubanite lamellae suggest that the temperature at which they were formed ranged between 250 to 550°C.

The geochemical abundance of the major oxides, viz, SiO_2, CaO, MgO and TiO_2 are showing decreasing trend towards the lode whereas, Al_2O_3, Na_2O, MnO and P_2O_5 are showing slightly increasing tendency towards the lode and Fe_2O_3 is showing appreciable increasing tendency towards the lode.

The trace elements like Pb, Zn, Cu, Co and Ni in the host rock show a tendency to increase in their abundance towards the ore bodies.

Whole rock samples have been also analysed. In most of the whole rock samples of the area, Co is invariably dominant over Ni.

Abundance of elements on the chalcopyrite, pyrrhotite, pyrite, sphalerite and galena is determined on Electron Probe Microanalysis.

The average Co: Ni ratio in the chalcopyrite is 7.6, average Co: Ni ratio in pyrrhotite is more than one and the Co: Ni ratio in pyrite ranges from 3.2 to 5.8.

On the basis of average Co: Ni ratio in chalcopyrite, pyrrhotite and pyrite, the sulphide ores of the area could be regarded as hydrothermal deposits.

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1998

DEDICATED
TO
MY PARENTS

Ref. No...../Geol. Dated..

CERTIFICATE

This is to certify that **Mr. Mohd. Wakeel** has worked on the problem "**Base Metal Mineralisation In Sawar-Bajta Belt, District Ajmer, Rajasthan**" under my supervision as a student of Ph.D.

This work is his original contribution and has not been published and submitted for any degree in India or elsewhere. He is allowed to submit the same in the form of thesis for the award of the degree of "**Doctor of Philosophy**".

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Date : August 31, 1998

(MOHD. WAKEEL)

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CHAPTER - 1

INTRODUCTION

INTRODUCTION

Base metals come on the lower side of the electrochemical series of the metals in comparison to the noble metals which are placed on the upper side of the electrochemical series. They also get easily weathered when they are exposed to the atmosphere. The common metals come under the base metals are copper (Cu), lead (Pb), zinc (Zn), antimony (Sb) and bismuth (Bi). In comparison to the base metals, noble metals are not effected by the corrosion.

Base metals occur on the crust of the earth and according to Goldsthmidt (1937b) igneous rocks contain 70 gram/ton Cu, 132 gram/ton Zn, 16 gram/ton Pb, 0.2 gram/ton Bi and 1 gram/ton Sb. The quantity of these metals in meteorites is copper as 170 gram/ton, zinc as 138 gram/ton and lead as 11 gram/ton. The content of copper in the early magmatic sulphide is much higher than in the meteorite sulphide phase. The sulphide bodies of the pyrrhotite, pentlandite paragenesis regularly contain notable amounts of copper, with the average Ni:Cu ratio being 2:1. The explanation is that the general geochemical character of copper is mainly chalcophile, but in the meteorites copper has a notable siderophile tendency.

Zinc is strongly enriched in early magmatic sulphides. However, zinc is also enriched in late magmatic sulphides and in the residual solutions formed during the crystallization of the early magmatic sulphides.

According to Sandell and Goldich (1943), the average copper content of basic igneous rocks is 149 gram/ton, in intermediate igneous rocks 38 gram/ton and in acid igneous rock is 16 gram/ton. Sulphides and sulphosalts are the most important copper minerals and it is evident that by far the greatest part of copper in the upper lithosphere is bound within these minerals. According to surveys by Newhouse (1936) and Ramdohr (1940), copper is chiefly or entirely present as chalcopyrite ($CuFeS_2$) in unaltered normal igneous rocks belonging to the main stage of crystallization, wherein, only a smaller amount is found as Bornite (Cu_5FeS_4) and cubanite ($CuFe_2S_3$).

A small amount of copper remains in the oceans, but its content therein is kept low, owing to the absorption, or possible combination with the marine organisms.

Copper possesses the definite biophile properties. It is invariably found as a microconstituent of plants and animals. In plants it stimulates the growth when present in small amount but, is poisonous in large quantities. However some plants are able to concentrate copper, for example Leguminous plants are rich in this metal. Erkama (1947) states that copper in plants may be present entirely as protein complexes. Vogt (1942) has found that Viscaria alpina and Melandrium dioecum growing in copper-poisoned soil may endure a copper content as high as 6,500 gram/ton, where the normal content of soil being 20 gram/ton. The two plants are consequently

able to survive in the neighbourhood of out cropping copper ore bodies, copper mines etc, where all other vegetation will perish. Copper is also enriched in coal ashes. It is further concentrated in some minerals, the oysters being exceptionally rich, with a maximum of 60gram/ton copper in fresh tissue.

Hemocuprein is a copper protein compound which is believed to be a factor in the synthesis of haemoglobin. Copper is also an essential microcostituent in the growth of many grazing animals and an oxidation catalyst in some enzymes which actually are copper protein complexes.

Although much copper concentrated by marine organisms remains in organic circulation, a considerable proportion must have been deposited during the geological history of the earth in the sediments, rich in organic matter. Thus, copper becomes enriched in bituminous substances and sapropelic sediments. Native copper falls in sediments, and the peat bogs are believed to be formed by microorganisms, able to reduce cupric sulphate solutions.

Highest concentration of zinc met in the sulphide phase of meteorites, whereas the second highest value being found in igneous rocks. The silicate meteorites contain considerably lower quantity of zinc.

In the early magmatic sulphides, the amount of zinc is relatively low. Zinc is the more substantial constituent of those parts of the sulphide ores which were last to crystallise and which often intrude the surrounding rocks in the form of apophyses. Along the with cadmium, sphalerite may carry iron, manganese, cobalt, gallium, germanium, indium and thallium. These impurities may be used as indicators of temprature of formation of the sphalerites.

Notwithstanding the relatively great ionic radius, zinc in its compounds, is always 4-co-ordinated with respect to oxygen. This manner of occurrence of zinc causes its minerals, in general, to have relatively loosely packed structures. During the magmatic differentiation zinc, and cadmium together with many other elements remain largely in the residual melts and solution throughout the main stage of crystallization and the pegmatitic stage. Lundegardh (1946) found the highest zinc contents in the later more acidic products of differentiation. Sphalerite with the zinc content of 67 percent, is the most important ore mineral of zinc.

Although, shales containing organic remians are often rich in zinc, the highest concentration of this metal occurs in places where the production of hydrogen sulphide by decaying organism has been rather weak. Zinc remains, in part, in the sea water and is finally deposited in carbonate sediments. The low concentration of zinc stimulates the growth of plant but, in large quantities it is very toxic to most of the plants. Sometimes, it is

concentrated by plants with the maximum of 16 percent zinc and is reported in the ashes of Thlaspi calaminate. Zinc is also enriched in coal ashes. In addition, it becomes fixed in soil, and in this process some micro-organisms seem to be of importance. In marine organisms, the highest zinc content is found in oysters. Zinc is also essential for bigger animals.

In the lithosphere lead (Pb) shows rather a pronounced affinity for sulphur and also for oxygen. A very considerable part of lead in igneous rocks occurs as galena. Pb^{2+} may replace Ca^{2+} in minerals, formed at the lower temperatures. Aragonite may contain upto 18 percent $PbCo_3$. Otteman (1941) reported 100 gram/ton Pb in epidote, upto 77 gram/ton in biotite and 50 gram/ton in fluorite. Galena with 86.5 percent Pb, being the most prominent of all. In addition, it is the most important silver minerals (upto 2 percent Ag).

The relatively much lead is present in the sea water. It is precipitated, as sulphide, in the sediments rich in organic remains and becomes absorbed and enriched in hydrolyzates and oxidates.

Lead is present in the ashes of many land and sea plants and is enriched in coal ashes. It is also found in many marine animals especially corals, crustacea and molluscs and an erratic microconstituent of bigger animals. However, it probably has only a toxicological function.

Antimony and Bismuth are notably the rear constituents of the upper lithosphere. Only a small amount of antimony and bismuth is found in the rocks and minerals belonging to the early and main stage of magmatic crytallization.

Although,copper is widely distributed. Eighty percent of the world supply, emanates from six regions viz; the south-western United States, the USSR, the Andean belt, the central African belt and the Canadian shield.

The Utah copper mine at Bingham, Utah, is the greatest copper producing mine of the world. These are the porphyry copper deposits of low grade; they are associated with the stocklike intrusions of monzonitic porphyries of Mesozoic or Tertiary age and they are disseminated replacement and veinlets in porphyry; volcanics or intruded schist. Lake superior copper district, Michigan is the outstanding deposit of the native copper.

At Kupferschiefer, Mansfeld in Germany; where a thin, but a widespread cupriferous bed of black shale of 40 centimeter thick, has been mined for just 2 to 3 percent copper content. The origin of the ore bed is controversial. Advocates of syngenetic sedimentary origin hold, that the ore was deposited in a shallow sea where sulphate reducing bacteria, provided the sulphur as H_2S that reduced and precipitated the sulphides of predominantly copper, also lead, zinc and some silver metals and pyrite. The

sources of the metal has recently been suggested as an exhalative source such as submarine hot spring solutions that might be widespread enough to provide a thin cupriferous formation, covering an area of 6000 square kilometers.

Zambian copper belt, Africa, also contains a huge amount of copper. Lead and zinc are commonly associated with copper and other base sulphides. Despite the chemical dissimilarity, geological conditions favour the formation of lead and zinc together. The five countries which contribute produce more than the two third of the world production of lead, are USA, Russia, Australia, Canada and Mexico. Some important examples of lead and zinc deposits are as follows :

Stratabound deposits of syngenetic origin;

Example : Kuperschiefer, Germany.

Stratabound deposits of epigenetic origin;

Examples : Tristate, upper Mississippi valley, USA and southeast Massouri, USA.

Volcano sedimentary deposits;

Examples : Kuroko, Japan; Broken hill, NSW Australia; Mount Isa, Australia and Kid Creek, Canada.

Replacement deposits;

Examples : Cerro-de-pasco, Peru and Bingham, Utah, USA.

About half of the world lead and zinc comes only from the North American continent.

USE OF BASE METALS :

Copper is one of the very essential mineral of modern industries. It is normally a metal of prosperity which is used when electrical expansion takes place but, it is also an essential metal of battlefields. Most wires and electrical equipments are made up of pure copper and a considerable alloy of copper is used, chiefly as brass and bronze. Lead and zinc rank next to copper as essential non-ferrous metals in the modern industries. Lead is used over other materials because of its demonstrated corrosion resistance over a wide range of conditions and after a long and useful life, it has a high salvage value. Zinc is used in galvanizing, dye-casting alloyed with copper to form brass, wire, tubes and pipes and other uses.

Though, India is deficient in base metals and depends upon imports from other countries to overcome the demand. However, still there are some important base metal deposits in India.

Important base metal deposits of India are;

I. Ingaldhal copper deposits of Karnataka.

II. Singhbhum copper belt of Bihar.

III. Khetri copper belt of Rajasthan.

IV. Zawar Pb-Zn belt of Rajasthan.

V. Pur-Banera lead-zinc and copper belt of Rajasthan.

VI. Rajpura-Dariba multimetal deposits of Rajasthan.

The basement rocks contain a major lead-zinc deposit in the Rampur Agucha area. The ore mineralisation in this area is associated with the garnet-graphite-Sillimanite bearing biotite schists, gneisses, calc granulites and amphibolites.

The most important lead-zinc mineralisation in the Aravalli Supergroup is at Zawar, district Udaipur, Rajasthan. The Zawar group of deposits are stratiform and stratabound in nature and hosted within the carbonates.

Another polymetallic sulphide ore mineralisation in the Aravalli rocks occur along Rajpura-Dariba-Buthumni belt. Rajpura-Dariba ores demonstrate a classical multi-metal association of Zn-Pb-Cu-Ag-Cd-As-P-F-S, with minor Au, Mo, In and Hg. The ore bodies occur as broad layers of mainly Pb-Zn Cu sulphides, conformable to bedding of associated graphite mica schists and calc-silicates.

In the Bhilwara region, the Aravalli Supergroup contains a number of polymetallic sulphide deposits associated with the metasedimentary rocks.

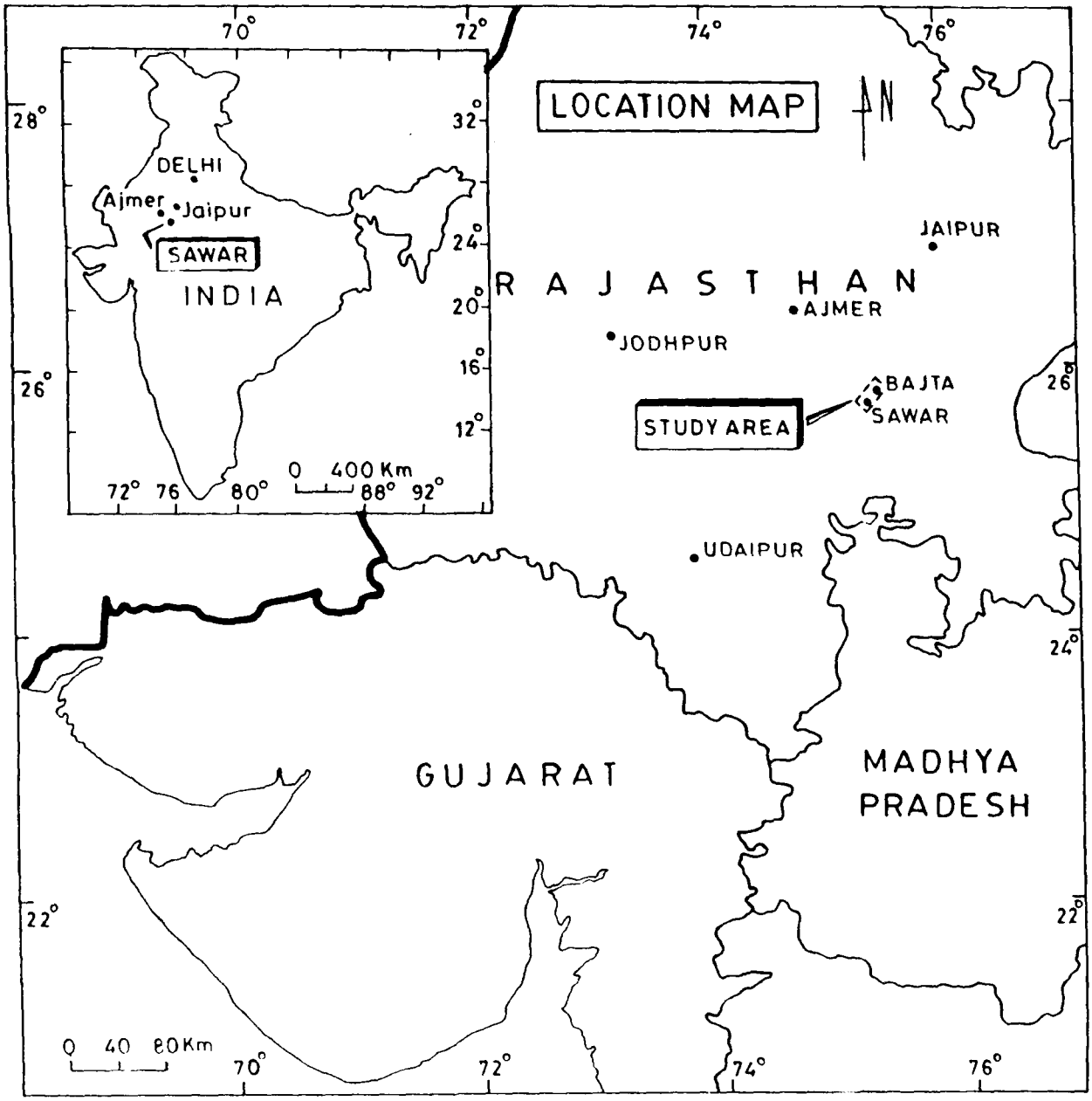

LOCATION MAP
N
DELHI
Ajmer
Jaipur
SAWAR
INDIA
0 400 Km
JAIPUR
RAJASTHAN
AJMER
JODHPUR
BAJTA
SAWAR
STUDY AREA
UDAIPUR
GUJARAT
MADHYA PRADESH
0 40 80Km
70°
72°
74°
76°
28°
26°
24°
22°
32°
20°
16°
12°
72° 76 80° 88° 92°

Fig. 1

The rocks of Delhi Supergroup contain two major domains of sulphide ore mineralisation, one in the northeastern part, which includes copper ore deposits of Khetri and Kho-Dariba, and the other in the southeastern part, containing the polymetallic sulphide ore mineralisation along Ajari-Basantgarh Ambaji-Deri.

LOCATION :

The Sawar-Bajta area of Ajmer district, is situated about 140 kilometers south-southwest of Jaipur (Fig.1). The area extends between the latitude N 25^0 44' to 25^0 51'N and between longitude 75^0 12'to 75^0 18'E, and falls under the Survey of India Toposheet Nos. 450/1 and 480/5.

ACCESSIBILITY :

A state highway from Jaipur to Kekri passes through Tonk and Malpura. The Ajmer-Nasirabad-Deoli-Kota highway passes through Kekri. Sawar village is connected with Kekri by a pitch road of 25 kms length. A fair weather road, passing through the Ramthala village and the Khari river bed, connects the Bajta village to the Ajmer-Nasirabad-Deoli-Kota highway (Toposheet No. 450/5). Several cart-tracks provide access to the field sites.

PHYSIOGRAPHY, DRAINAGE AND CLIMATE :

A series of small hills from NNE-SSW trending, 13 kilometer long range, extending from Bajta village in the north to Sawar village in the south. These hills generally rise, 50 to 150 meters above the surrounding plains. The general elevation of the plains is 330 meters above the mean sea level and the highest point of the area is the Kantola-Dunger peak at 580 meter above mean sea level near Ghatiali (Toposheet No. 450/5). Several small nallahs collect the precipitation of the area and flow to the Khari river, which is passing through north of the Bajta village. Earthen dams and embankments across many of these nallahs have been constructed for irrigation purpose. The hill ranges around the Ghatiali village fall within the Ghatiali reserve forest. This forest is now very lean with only few isolated trees (mainly Palas, Gular, Khejri, Dhokra, Orinja, Ker and Neem) surviving deforestation. The gently undulating plains of the area are over grazed and support rare shrubs and bushes of Kheef, Bar, Bilaiti Bamol (Juliflora) and cacti. Rabbits, jackals and wild cats are the only wild animals of the area. Snakes and scorpions which remain dormant in the winter season are the usual field hazards in the summer and monsoon season. Semi-desertic climate conditions with very hot summer (temperature upto 50^0C) and cold winter (4 to 5^0C night temperature) prevail in this area.

Rocks of the Sawar Group are poor reservoir of ground water and the impure marble formation make the rocky surface unsuitable for cultivation. Few wells within the schist horizons of the Sawar Group provide moderate quantity of ground water. The gneissic country surrounding the metasedimentary zone forms a fertile plain with thick accumulation of

alluvium. Storage and yield of ground water in this terrain is high which support the rich cultivation.

PREVIOUS WORK :

Geology of the Sawar-Bajta area was briefly described by Pascoe (1924), who reported that the Sawar hills form an interesting isolated area of severely folded Delhi rocks, the rock facies comprising quartzites, mica schists and limestones. Later, Pascoe (1965) briefly discussed the stratigraphic correlation of the Sawar rocks. Ore minerals occur in the form of galena veins near Sawar and was first reported by Bhola (1935). Jain (1963) quoted in Jain and Devapriyan (1964), examined the ore zones and recommended a detailed geophysical and geochemical investigation of the area.

Prospecting for basemetal in the Sawar-Bajta area was started by Jain and Devapriyan (1964, 65, 66, 67, 68, 69), who described several small occurrences of lead-zinc from this metasedimentary belt. Exploration by drilling in the Sawar, Tikhi and Govindpura area was started in April, 1967 and was continued till 1970-71(Devapriyan, 1971) from where 0.85 metric tonnes of ore reserve with 3.72% Pb and Zn in the Sawar area and 1.62 metric tonnes of ore reserve with 4.04% Pb and Zn in Tikhi area were reported. Devapriyan recommended, further drilling in the Sawar, Tikhi and Ganeshpura area. Ray (1974) put forward the theory of inversion of fold

hinges on the basis of structure of the Sawar Bajta area and Ray (1988) also worked on the structures of the Bajta area and their control on copper mineralisation.

PURPOSE OF WORK :

The present investigation has been planned to study the lithostratigraphy, petrography and geochemistry of the host rocks of base metals in the Sawar-Bajta area. The purpose of present work is also to investigate the mode of occurrence, mineralogy and geochemistry of the base metals of the study area and to suggest their probable source and origin.

METHODS AND PRESENTATION OF THE WORK :

1. FIELD INVESTIGATIONS :

The area under investigation has been thoroughly surveyed with the purpose of geological mapping and collection of samples from the outcrops as well as from the bore holes.

i)Geological mapping :

The geological map of the Sawar-Bajta area has been prepared on the scale 1:50,000. The minor structures were recorded in detail and the contacts of different lithounits were plotted carefully.

ii)Collection of surface rock samples :

Several traverses of the study area were taken to collect the desired samples along as well as across the general strike of the different lithounits. About 200 samples of rocks were collected systematically on a grid and efforts were made to collect the unweathered samples.

iii)Collection of bore hole samples :

About 75 ore samples were collected from the bore holes. About 70 samples of the host rocks were also collected from the bore holes .

2. LABORATORY INVESTIGATIONS :

i)Petrographic and Mineragraphic Studies

Petrography and mineragraphy studies of thin sections of rocks and polished blocks were carried out under the transmitted and reflected light, respectively.

ii)Chemical Analysis

Systematic analysis of rocks and ore samples for the determination of major and minor oxides and the trace elements were carried out by using the Atomic Absorption Spectrophotometer. The ore samples have been studied

under electron probe microanalysis to determine the major and trace elements.

3. ANALYTICAL PROCEDURE :

On the basis of thin section study, a total number of 40 rock samples were finally selected for chemical analysis on Atomic Absorption Spectrophotometer (Fig.3). Seventy five samples of mineralised zones have been studied under the reflected microscope and finally, their polished blocks were selected to study them under the Electron Probe Microanalysis for chalcopyrite, pyrrhotite, pyrite, sphalerite and galena.

SiO2, Al2O3, Fe2O3, TiO2, MnO, P2O5 were determined at different wavelengths on the Perkin Elmer, UV/Vis Spectrophotometer; (Model: Lamda 3B), CaO and MgO were determined through titration method with the standard dichromate solution by using diphenylamine sulphonic acid as indicator.

Na2O and K2O were determined on EEL, Flame Photometer. Loss On Ignition (LOI) of the samples was determined by heating the sample powder in glass tubes at about 700°C . The solution for the determination of Cu, Pb, Zn, Ni, Co, Mn, Cr, Bi etc. was prepared by dissolving one gram of sample powder in 10ml. of 1:1 HNO3 and diluting it to 100ml. with distilled water. The trace elements were determined by using the Atomic Absorption

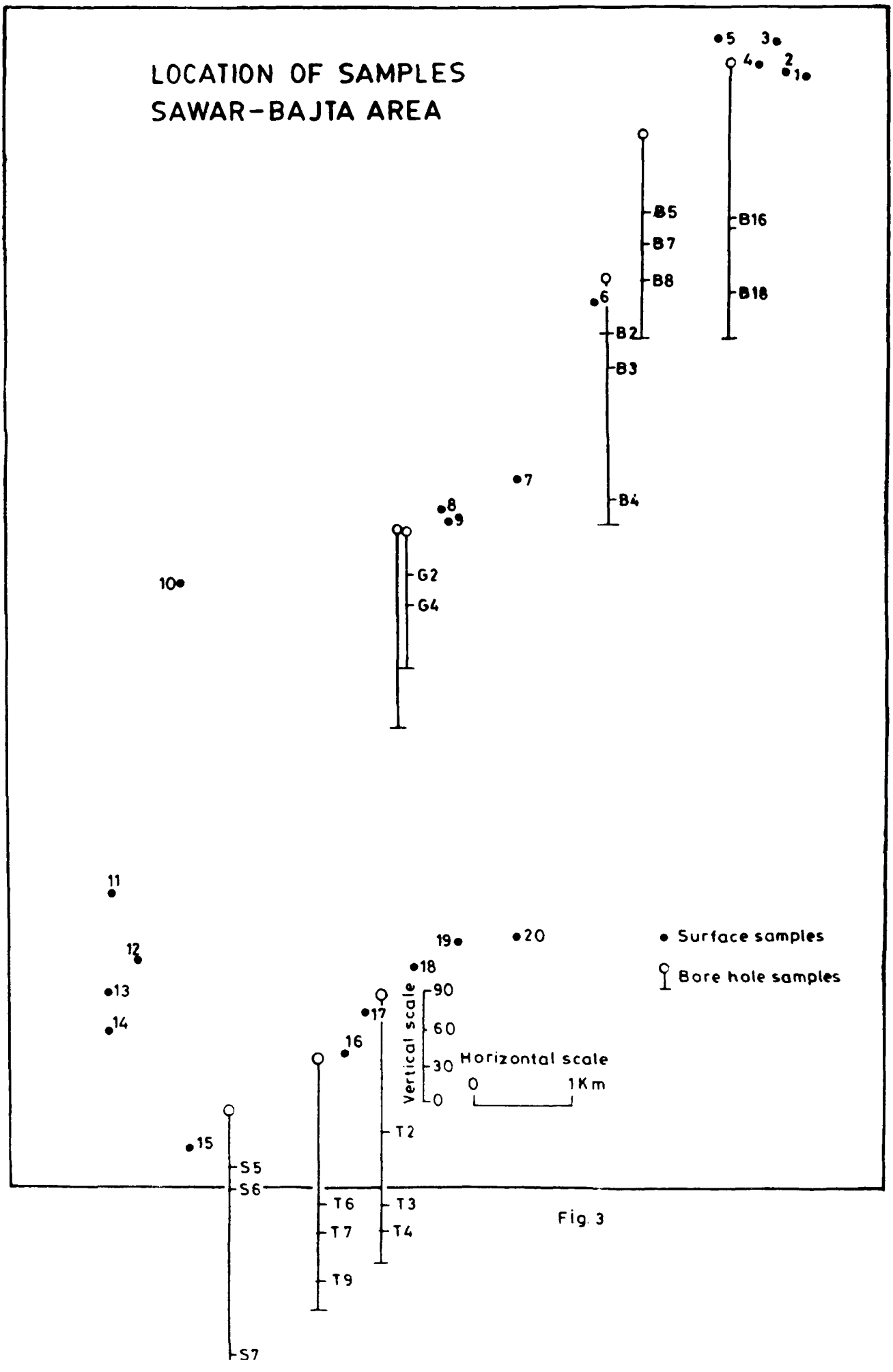

LOCATION OF SAMPLES
SAWAR-BAJTA AREA
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
B2
B3
B4
B5
B7
B8
B16
B18
G2
G4
T2
T3
T4
T6
T7
T9
S5
S6
S7
Vertical scale
90
60
30
0
Horizontal scale
0
1 Km
• Surface samples
Bore hole samples

Fig. 3

Spectrophotometer (Model : 902, GBC scientific equipment Pvt. Ltd.). The ore samples for the determination of major and minor elements were studied on Electron Probe Microanalysis, (Model : JXA-8600 M Superprobe), Instruments Make : JEOL, Beam current:50 nA, Beam diameter:5□m, Acceleration Voltage : 20 kv, SPI, Canada-standard using multistandard Instrumental correction : ZAF Correction .

CHAPTER - 2

REGIONAL FRAMEWORK OF ARAVALLI-DELHI BELT

REGIONAL FRAMEWORK OF ARAVALLI-DELHI BELT

The NNE trending Aravalli-Delhi belt of northwestern India extends from Delhi to Palanpur over a strike length of 750 km and have an average width of 200 km (Roy and Paliwal, 1981; Powar and Patwardhan, 1984; Naqvi and Rogers, 1987; Deb and Sarkar, 1990).

The Aravalli supracrustal rocks are different form those of other parts of the Indian shield. The Dharwar supracrustal rocks are Archaean and predominantly mafic/ultramafic schists, chemogenic sediments, argillites, volcaniclastics and graywackes with subordinate amounts of detrital orthoquartzites and carbonates. In contrast the Aravalli supracrustal rocks are mostly Proterozoic and consists of phyllites and graywackes with abundant orthoquartzites, carbonates, and minor mafic/ultramafic schists. Another difference is shown by the distribution of iron. Except in the Bijawer suite and in minor deposits of the Delhi Supergroup, Banded Iron Formations are almost absent from the Aravalli Craton. The Dharwar, Singhbhum and Bhandra Cratons however, contain major Banded Iron Formation deposits. Widespread development of stromatolites and phosphorites is also confined to the Aravalli Craton, showing abundant availability of photosynthetic oxygen during the Aravalli time. The presence of phosphorite requires oxygen and the absence of Banded Iron Formation shows that Aravalli Basins were not supplied with the iron to be oxidized

and deposited, which can be attributed to the negligible subaquous volcanic and the sialic composition of the source (Naqvi & Rogers 1987).

Heron (1953) was perhaps the earliest one to carry out the regional geological investigations and recognised the lithotectonic zones viz; Banded Gneissic Complex (BGC), Aravalli, Raialo, and Delhi Series, the Banded Gneissic Complex of the Aravalli Delhi Belt was originally defined as suite of pre-Aravalli metasediments, migmatites, aplites and metabasic rocks (Heron, 1953; Sen, 1983). Evidence of an unconformity between the BGC and the overlying supracrustal suites has been widely proposed (Heron,1953; Poddar, 1966; Naha and Majumdar, 1971b). Crookshank (1948) stated that the BGC has invaded the Aravalli sediments and incorporated them partly as enclaves. Sharma (1983) described the BGC as polymetamorphic basement containing older supracrustal rocks. Naha and Roy (1983) showed structural concordance between the BGC and the Aravalli Raialo suite and concluded that at least a part of the BGC formed by the migmatization of metasediments of the Aravalli sequence . The BGC has been affected by several periods of deformation and metamorphism (Naha and Holyburton , 1974 and Roy, 1985)

The BGC consists of granite gneisses, paragneisses, charnockites, calc-silicates, quartzites, Schists, granites, pegmatites and aplites (Sharma and Narayna 1975a, 1975b, 1975c; Sharma and Ray 1979, 1980; Pandya, 1981 and Sharma 1982).

The matesediments surrounded by the granite or gneissic component of the BGC along an extended belt of Karera and the west of the great boundary fault, was designated as Bhilwara Supergroup (Raja Rao et.al., 1971 and Raja Rao, 1976). The Geological Survey of India (1977) defined the Bhilwara Supergroup as the BGC, exposed in the Karera area and Hindoli Group. Gupta et.al. (1980) redefined the term (Shown in table-1 and as depicted in Fig.2).

Many evidences have been used by various workers to provide approximate date of the BGC. Sm-Nd isochron date of 3.5 ga and a Rb-Sr whole isochron date of 3.0 ga (recorded in Deb and Sarkar, 1990). The Untala Gramite, which intrude the BGC was dated as 2950 +/- 150 m.y. by Rb-Sr methods (Chaudhry et.al., 1984) and the Berach Granite was dated at 2600 m.y. by the Pb-U techniques (Sivaraman and Odom,1982).

Crawford (1970) found Rb-Sr isochrons for the Berach Granite as 2550 m.y. and the BGC as 2000 m.y. Amphibolites and grey gneisses near Udaipur define on Sm-Nd isochron giving an age of 3500 m.y. (Mc Dougall, et. al., 1983)

BGC is overlain by Aravalli Supergroup. Aravalli and Jharol parts are grouped together and named as the Aravalli-Jharoal Belt as they represent two segments of a single depositional basin, share the same deformational

Table 1 : Stratigraphic Classification of Aravalli Region.
(After Gupta et.al., 1980)

P	DELHI	**DELHI SUPERGROUP**			
R	**GEOLOGICAL**	Punagarh Group			Sindreth Group
O	**CYCLE**	Sirohi Group			
T	**(2000-800 m.y.?)**	Kumbhalgarh Group			Ajabgarh Group
E		Gogunda Group			Alwer Group
R					
O	ARAVALLI	**ARAVALLI SUPERGROUP**			
Z	GEOLOGICAL	Champaner Group			
O	CYCLE	Lunavada Group			
I	**(2500-2000 m.y.)**	Jharol Group	Dovda Group		Nathdwara Group
C		Barilake Group			
		Udaipur Group			
		Debari Group			
A					
R	**BHILWARA**	**BHILWARA SUPERGROUP**			
C	**GEOLOGICAL**	Ranthambhor Group			
H	**CYCLE**	**Rajpur - Dariba**	**Pur-Banera**	**Jahazpur**	**Sawar**
A	**(>2500 m.y.)**	**Group**	**Group**	**Group**	**Group**
E					
A		Hindoli	Mangalwar		Sandmata
N		Group	Complex		Complex

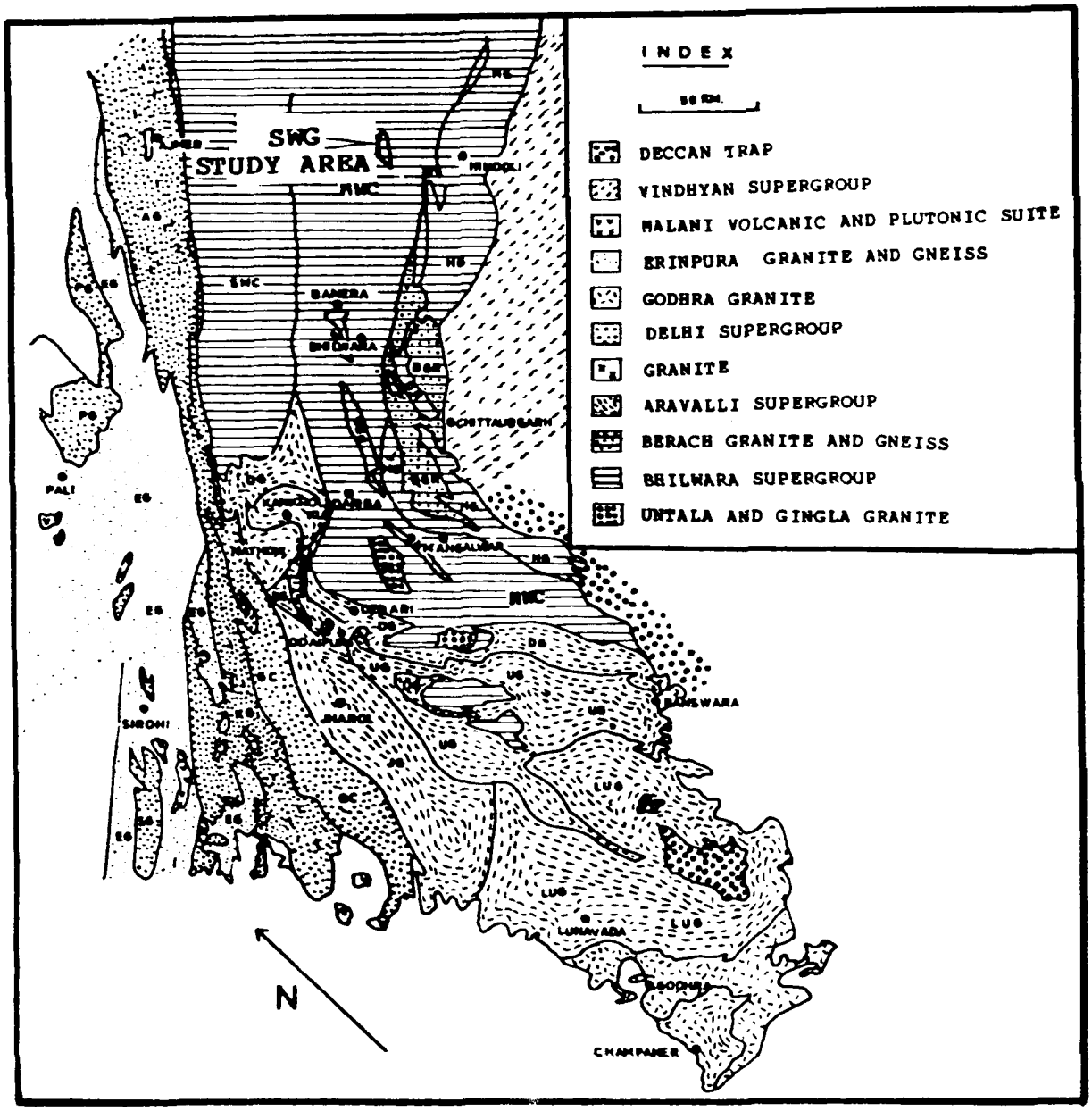


Fig.2 Geological map of the Aravalli region compiled by Gupta et al., (1980). Explanation: SMC-Sandmata Complex; MNC-Mangalwar Complex; HG-Hindoli Group; SWG-Sawar Group; JHG-Jahazpur Group; PBG-Pur-Banera Group; RG-Rajpura-Dariba Group; DG-Debari Group; UG-Udaipur Group; BG-Bari Lake Group; KG-Kumbhalgarh Group; KLG-Kankroli Group; NG-Nathdwara Group; DG-Dovda Group; JG-Jharol Group; LUG-Lunavada Group; CG-Champaner Group; KG-Kumbhalgarh Group; SG-Sirohi Group; PG-Punagarh Group.

history and have similar tectonic trends (Goodwin, 1991). Aravalli Supergroup is dated as Early Proterozoic (2500-2000my).

The Geological Survey of India (1977) divided the Aravalli Supergroup into two parts. They designated the Udaipur Group as a lower unit, which contains quartzites, matavolcanic rocks, arkosic grits, conglomerates, carboneceous phyllites which contain bands of dolomites and quartzites. Stromatolite occur in the bands of dolomite. The upper unit of the Aravalli Supergroup is designated as the Jharol Group, which lies unconformably over the Udaipur Group and contains a thick sequence of phyllites and quartzites. Jharol Group was designated formerly as the Raialo series (Heron,1953).

Roy and Paliwal (1981) divided the Aravalli sequence into two distinct different facies, representing deep sea and near shore shelf environments respectively. The shelf sequence starts with mafic volcanic flows and tuffs and quartzites. These are overlain by dolomites, quartzites, phyllites, carbonaceous phyllites and stromatolitic rock phosphates. This carbonate sequence passes upwards into greywacke-phyllite-lithic arenite in the distal parts and conglomarates - arkose - orthoquartzite in the epicontinental and shelf areas .

Delhi rocks unconformably overlie the Older Bhilwara-Banded Gneissic Complex basement. In the narrow and the more tightly constrained

southwestern part, Delhi rocks are in tectonic contact with the Aravalli Supergroup in the east, and with Erinpura Granite (740Ma old) and Canozoic cover in the west (Naqvi and Rogers,1987; Singh, 1988 and Deb et.al., 1989). The Delhi suite is divided by some authors into the Raialo , Alwar and the Ajabgarh formations. Other workers placed the Raialo formation in the Jharol Group of the Aravalli Supergroup.

The Delhi Supergroup consists of quartzites, conglomerates, arkose, slates, phyllites, schists, limestones, marbles, gneisses and amphibolites.

In Delhi Supergroup, the Khetri Copper Belt is intruded by the Udaipur and Saladipura granites which have an isochron age of 1480 m.y. (Gopalan et.al., 1979a).

Although granitic intusives into the Delhi Supergroup in the northeastern region yield an age of about 1700 to 1500 m.y. Granitic intrusives into the main Aravalli Moutain further south, give a much younger age as of 850+/- 50 m.y. (Sastry et.al.,1984). The widely seperated ages are interpreted as the two tectonothermal episodes within the apparently similar Delhi rocks or the development of the Delhi suite in two independent basins that were widely seperated with space and time(Naqvi and Roger 1987).

LOCATION OF THE AREA IN THE REGIONAL FRAMEWORK

Different geological maps show that the central Rajasthan contains some linear zones of matasediments like Jahazpur, Pur-Banera, Rajpur-Dariba and Sawar. These linear zones consist of mainly calcareous and calc-magnesian silicates, schists and quartzites. These metasediments occur as enclave within granites and gneisses and granulites (Baned Gneissic Complex of Heron,1953; Mangalwar Complex and Sandmata Complex of Gupta et.al.,1980). Pascoe (1924) described the sandstone, quartzites, micaschist and limestones of the Sawar area as severely folded Delhi rocks. Later, Pascoe (965) correlated these metasediments with the Raialo series of Heron (1953). And this isolated outcrop zone is shown to be surrounded by alluvium. Gupta et.al., (1980) have proposed a different stratigraphic classification and included these metasediments within the Archaean-Bhilwara Supergroup, considering them to be older than the Proterozoic Aravalli and Delhi Supergroups. The dolomite, dolomitic marbles, quartzite and garnetiferous micaschists of the Sawar area have been placed by them in the Sawar Group and the rocks enveloping the Sawar Group have been included in the Mangalwar Complex.

The Sawar Group, consisting of four confomable lithostratigraphic units, have been mapped in the area shown in Fig.4. Stratigraphic sequence observed in the study area is as follows:

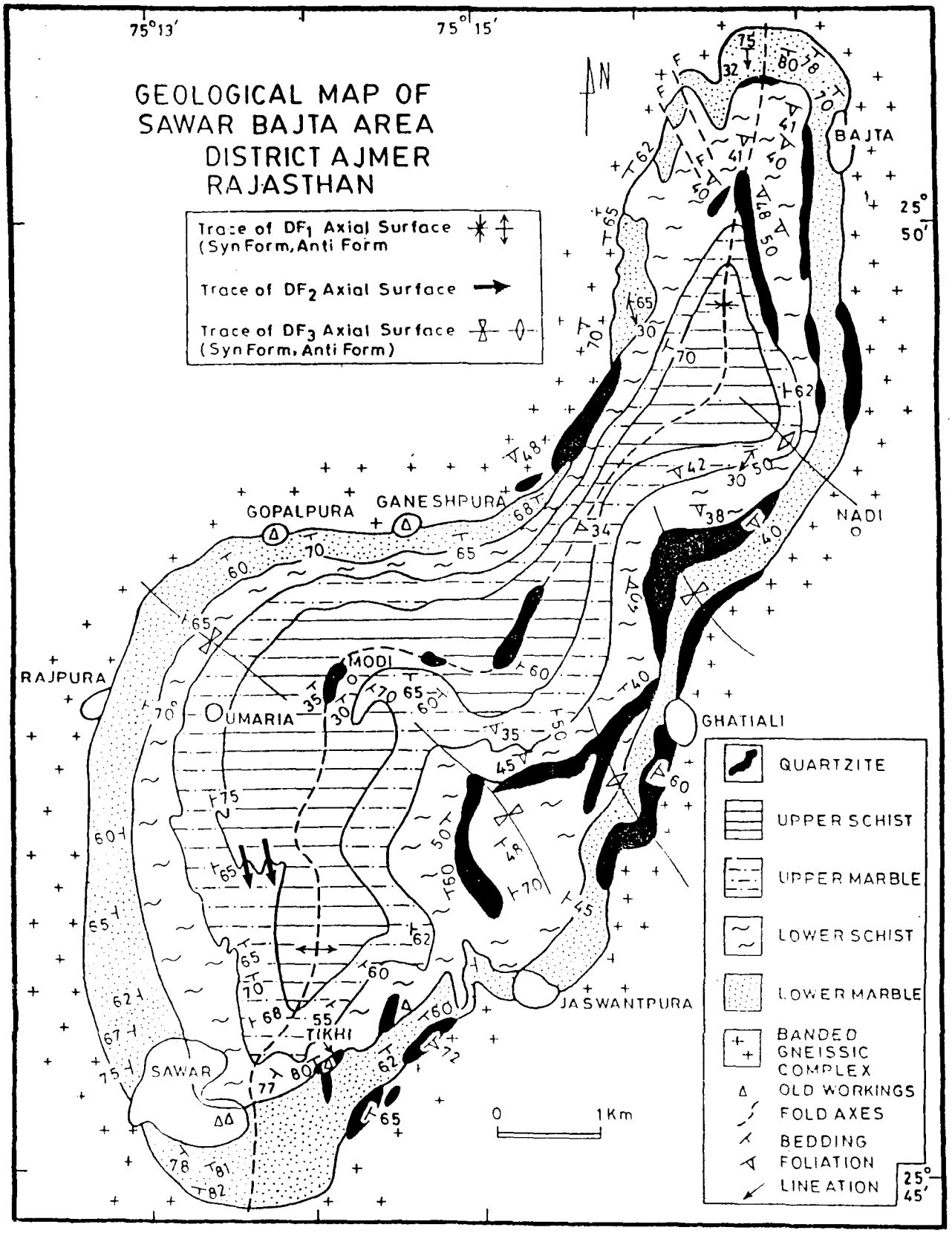

GEOLOGICAL MAP OF
SAWAR BAJTA AREA
DISTRICT AJMER
RAJASTHAN
75°13'
75°15'
25° 50'
25° 45'
N
Trace of DF1 Axial Surface (Syn Form, Anti Form
Trace of DF2 Axial Surface
Trace of DF3 Axial Surface (Syn Form, Anti Form)
BAJTA
NADI
GANESHPURA
GOPALPURA
MODI
UMARIA
RAJPURA
GHATIALI
JASWANTPURA
TIKHI
SAWAR
QUARTZITE
UPPER SCHIST
UPPER MARBLE
LOWER SCHIST
LOWER MARBLE
BANDED GNEISSIC COMPLEX
OLD WORKINGS
FOLD AXES
BEDDING
FOLIATION
LINEATION
0
1 Km

Fig. 4

Intrusives	Vein quartz and quartzite
Sawar Group	Upper Schist Upper Marble Lower Schist Lower Marble
Mangalwar Complex	Biotite schists, migmatites amphiolites,gneisses, quartz, garnet sillemanite rocks and quartzites.

The sequence is inverted in the southern part of the area with the Mangalwar Complex overlying the Sawar Group (Ray,1988). The sequence within the Sawar group is also inverted in this area. This is due to the inversion of fold hinge (Ray,1986).

Because of the scarcity of exposures, the contact between the Mangalwar Complex and the Sawar Group could not be studied properly. In the Tikhi- Jaswantpur-Ghatiali area, the contact between the lower marble and quartzites of the Mangalwar Complex could be seen, whereas in the Bajta area lower marble of Sawar Group grades to amphibole marbles, amphibolites and gneisses below. In the area between the Ganeshpura and Bajta the lower marble rests over the calc-gneisses, amphibolites and

migmatites, and in the area, between the Ghatiali and Khera, lower marble rests over the quartzite.

The Sawar Group lies conformably over the Mangalwar Complex and the contact between the Sawar Group and Mangalwar Complex is gradational. The contact has been obliterated perhaps because of matamorphism and granitisation.

The succession of the rocks at the base of the Sawar Group, observed in the Bajta area, is as follows.

Marble with patches and bands of amphibole

Mangalwar Complex	Migmatitic gneisses
	Granite gneisses
	Amphibolites
	Marble
	Migmatitic gneisses, Banded- gneisses
	Amphibolits

In the succession, which has been observed in the Bajta area, both the marbles are identical with the marbles of the lower marble which

suggests that a part of the marble has been converted into gneisses. In addition to this, marbles, calcareous amphibolites and quartzites occur at several places within the gneisses showing that a part of the Sawar Group has been changed to gneisses. Foliations in the gneisses and amphibolites observed parallel to the foliations in the lower marble.

These evidences suggest that the Sawar Group has been deposited with the formation of a shallow depression in the basement which is chiefly made up of granites and gneisses. In the beginning marls with evaporites, interbedded with the arkose, were deposited and forms the base of the Sawar Group. The deposition of the Sawar Group is followed by the deformation and metamorphism.

Description of the Rock Types:

An attempt has been made for a detailed study of differant rocks types in the area under investigation.

Mangalwar Complex:

Rocks of the Mangalwar Complex enclose the Sawar Group. The Sawar Group rests, at different places, on different rocks of Mangalwar Complex.

In the Tikhi area Mangalwar Complex is represented by the quartzites which are well foliated and bedded. Similarly, in the Jaswantpura and Ghatiali area, there is a contact between the quartzites of Mangalwar Complex and the lower marble, a member of Sawar Group.

In the Rajpura area there is no outcrop, of Mangalwar Complex but the rock dumps of wells near the lower marble contain quartz-feldspar biotite schists and biotite gneisses of Mangalwar Complex Similarly, the banded gneisses, schist and amphibolite bands, parallel to foliation, are present in the Ganeshpura area.

In the area between the Rajpura and Sawar, well dumps of quartz-garnet-sillimanite rocks represent the Mangalwar Complex.

In the Bajta areea Mangalwar Complex is represented by calc gneisses, schists and amphibolites.

Mica mining pits are also present within the Mangalwar Complex.

Sawar Group:

The Sawar Group consists of four major lithounits, which have been designated as the lower marble, lower schist, upper marble and the upper

schist. The lower marble and upper marble mainly consists of marble and these two units are well exposed but, the lower and upper schist are not well exposed, except few patchy exposures.

Lower Marble:

The lower marble is the lower limit of the Sawar Group. In the northern end, near Bajta village and in the southern end, near Jaswantpur village, the lower marble is of considerable thickness because of fold closure. Lower marble is coarse grained and hornblende, tremolite, diopside, muscovite and biotite are the main constituents of the marble. These quartzite bands are also present at several other localities. The colour of the marble varies from grey, white to green. Lower marble is the host rock for the base metal mineralisation in the Sawar-Bajta area.

Lower schist:

The lower schist of Sawar Group is well exposed near Bajta, where it is represented by quartz-biotite-sillimanite schist.

In the well dumps, this unit is represented by quartz-feldspar-biotite schists and also by feldspar-quartzite. Microcline is the dominant feldspar in schists and quartzites of lower schist.

Upper Marble:

The upper marble of Sawar Group is well exposed and is thickened at saveral places due to folding. This rock is very pronounced at the southern closure near Sawar. It mainly consists of marble. The colour of marble varies from white to grey. Calc-silicate rich compositional bands are very common in this formation. Calc-silicate bands are composed of tremolite, diopside and quartz. Because of compositional bands, this unit felicitated the study of structural features and fold geometry.

Upper Schist:

The upper schist of Sawar Group occurs at the central part of the Sawar-Bajta area. This unit is not well exposed except, near the Modi village, where this unit is represented by biotide-quartz schist and amphibole-quartzites.

Reef quartz and silicified quartzite:

The discontinuous lenticular bodies are of selicified quartzite are mapped along the upper as well as the lower contact of the lower marble. In the Tikhi-Jaswantpura-Ghatiali and Ghatiali-Khera area, there are prominent zones of silicified quartzite which are the part of mangalwar complex.

CHAPTER - 3

DEFORMATION STUDIES IN THE ARAVALLI-DELHI BELT

DEFORMATION STUDIES IN THE ARAVALLI-DELHI FOLD BELT

The deformation history of Aravalli-Delhi Proterozoic fold belt has been carried out by many workers (Straczek and Srikantan, 1966, Naha and Chaudhry, 1968; Roy, 1973; Naha and Halyburton, 1974; Roy, 1988 and Iqbaluddin, 1989) and their study revealed that the rocks of the Aravalli region have undergone polyphase deformation history.

The structural studies carried out by Roy (1973) and Naha and Halyburton (1974b) in the Protiozoic fold belt of Aravelli region, suggest that the rocks have undergone three phases of deformation showing AF1, AF2 and AF3 folding related to AD1, AD2 and AD3 deformation events.

Roy et.al., (1980) have described the geometry of folds in the metasedimentary sequence of Aravalli region. They have suggested that the AF1 folds are of reclined or inclined geometry with dominantly easterly or westerly plunge and these have been refolded by the two successive phases of folding which referred as AF2 and AF3, showing different attitudes of their axial planes. Paliwal (1988) has deciphered that AF2 folds are either upright or steeply inclined, varying in geometry from open to tight. Naha and Chaudhry (1968) and Mukhopadhyay and Dasgupta (1978) have recorded eyed folds showing the closed outcrop pattern. Roy (1988) has suggested that the AF3 folds, which refolded both the AF1 and AF2 folds,

were the axial planes of AF3 folds are transverse to AF1 and AF2 folds in the matasedimentary sequence of Aravalli Proterozoic fold belt.

Mukhopadhyay and Dasgupta (1978), Roday (1979), Bhola and Varadarajan (1981), Bhola and Soberwal (1982), Naha et.al., (1984) and Roy and Das (1985) have recorded three phases of folding in the Delhi rocks but, Banerjee and Mitra, (1977) and Roy (1974) argued that the first two deformations DF1 and DF2 belonging to the same generation.

The nomenclature, adopted for various structural elements in the rocks of the Aravalli Supergroup, has been assigned to AD1, AD2, AD3 etc., which represents deformative episodes of Aravalli tectonic system (Anon,1981). Similarly, the structural elements (Planar and linear structures and folds) recognised in the rocks of the Delhi Supergroup have been assigned DF1 (F1 folds of Delhi Supergroup). The deformational episodes of the Delhi tectonic system have been assigned DD1,DD2,DD3,DD4 (Anon, 1981).

The minor structures namely, planar and linear structures and folds of different geometries have been recorded. Further, the macro-structures namely, broad antiform and its complementary synformal structures and faults are also recorded in the rocks of the Sawar Group. In time, the stratigraphy of rocks of the Sawar Group can be correlated with the Pur-Banera Group, Jahazpur Group and Rajpura-Dariba Group. The analysed

macro and mesostructures have been enclosed in Fig.4, without mentioning alpha numerical terminology (Anon, 1981). For example, the recorded planar and linear structures and folds and cross-cutting relationship, the different generation has been recognised viz; F1, F2, F3 etc., corresponding to D1, D2, D3 deformative episodes of the Aravalli tectonic system.

Macrostructures of Sawar-Bajta Area:

The macrostructures of Sawar-Bajta belt are manifested by large scale fold geometry as a result of the three deformation episodes related to D1, D2 and D3 in the metasedimentary sequence of Sawar Group. The D3 deformation has caused banding of F1 and F2 axial planes.

A synformal fold closure near Bajta village and antiformal fold closure near Sawar village are the most dominant features of the map pattern. The northern end of the Sawar Group in Sawar-Bajta area is merked by a synformal fold closure near Bajta village whereas, the southern end is marked by an antiformal fold closure near Sawar village. The northern closure is because of antiform plunging 30-40° towords south and the southern closure is because of an antiform plunging 70-80° towards south. The Bajta synform and the Sawar antiform share a common axial surface and the antiform along its axial trend changes over to a synform.

Ray (1974), first observed the spectacular and unusual feature of 'plunge inversion' or 'inversion of fold hinge in Sawar-Bajta area.

Ray (1974) explained that superposed deformation by compression parallel to the axes of a set of folds unusually produces plunge reversals giving rise to the axial culminations and depressions. This deformation is primarily the rotation of the fold hinge in opposite directions on either sides of the later axial surface. If this rotation is inequal, one segment of the fold will plunge steeper as compared to the plunge of other segment. At one stage the segment rotating more will attain neutral geometry.

Ray (1974) termed this stage as 'critical stage' because upto this stage the fold geometry will be characterised by simple plunge reversals and antiform and synform will remain antiforms and synforms respectively along their axial trend. But, the rotation beyond this critical stage will produce plunge inversion and in the inverted segment the synform will be changed into antiform or vice versa. Moreover, in the inverted segment of the fold, the order of superposition will totally be reversed and successively older rocks will appear in the direction of plunge.

The 'plunge inversion' at Sawar area is the result of compression parallel to the axis of a N-S trending synform with upright or steeply inclined axial surface. The deformation producing the N-S trending synform, which is the earliest fold structure of the area, has been designated as D1

deformaton. The superposed N-S compression which, at first, produced plunge reversal and ultimately culminated in plunge inversion in the southern segment of the synform near Sawar, has been designated as D2 deformation. The F3 folds have been observed in the Sawar-Bajta area where they are marked by southeasterly trending folds, and is a product of subsequent deformation designated as D3 deformation .

The early folds of F1 generation are rarely observed in the Sawar-Bajta area. However, at places, few F1 folds are developed which are tight to isoclinal (plate 1a) and reclined at some places.

Stratification (So) defined by colour and compositional band is the earliest planar structure, developed in the matasedimentary rocks at the time of deformation. Although, intense folding and matamorphism have obliterated stratification in large part of the area and it is still recognized as marble and schist.

The first deformation of the rocks of the area resulted in the formation of a series of upright and steeply inclined isoclinal, tight and gentle folds (plate 1a). A fairly well developed crenulation cleavage has accompanied this deformation as the axial plane cleavege (plate-1b).

As a result of the second fold movement, several small and intermediate scale folds were formed (plate-2a and plate-2b). These folds are

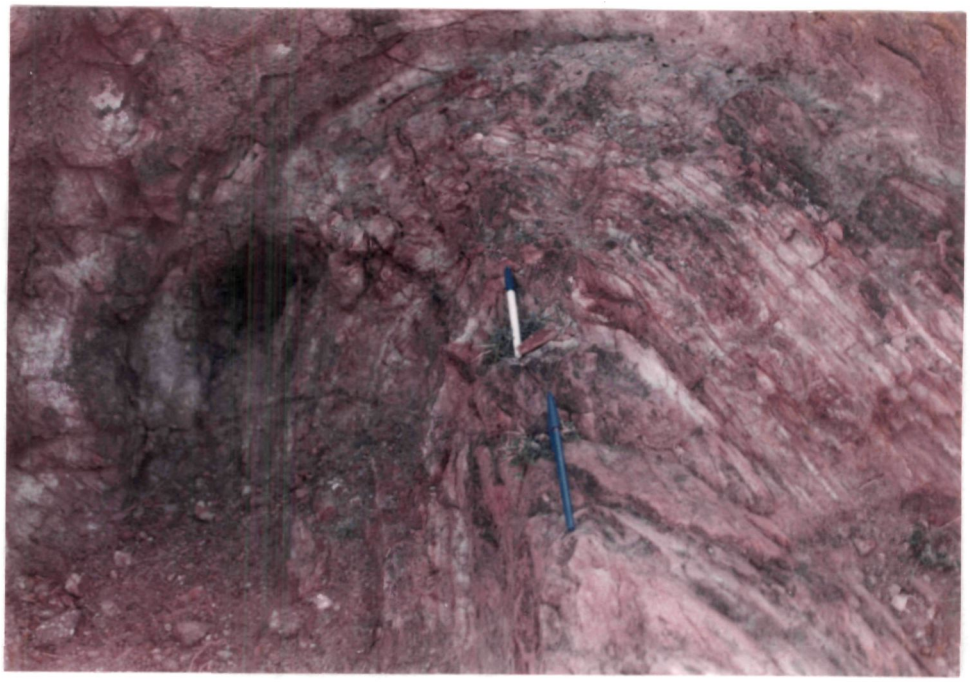
Plate 1

a) Field photograph showing isoclinal folds of first deformational episode (D1) in upper marble of Sawar group.

b) Field photograph showing isoclinal folds of first deformational episode (D1), axial plane cleavages are also seen in the upper marble of Sawar group.

PLATE 1

(a)



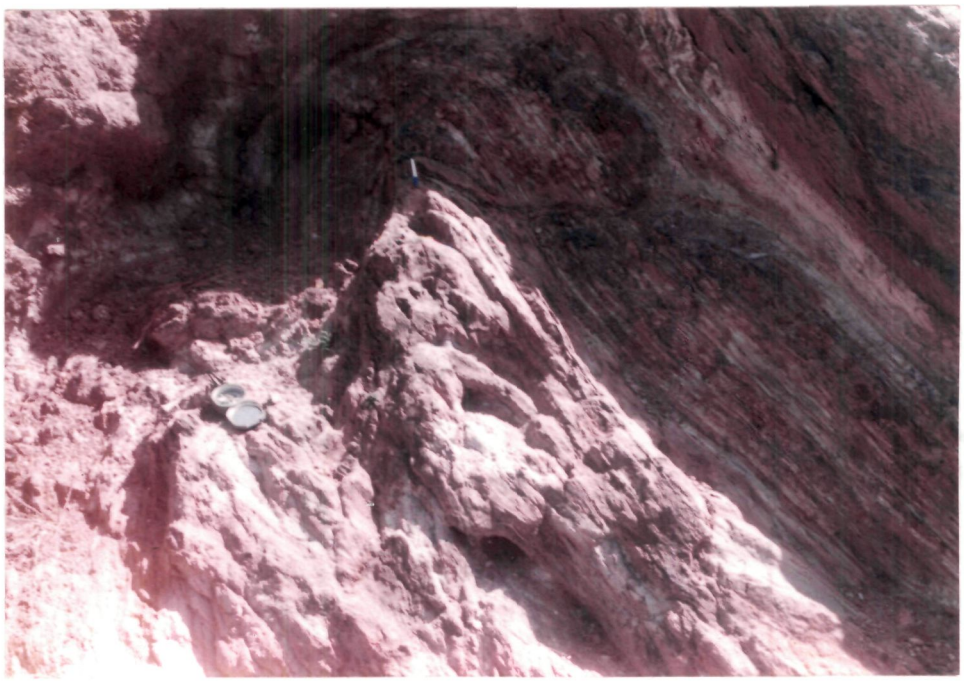
(b)

Plate 2

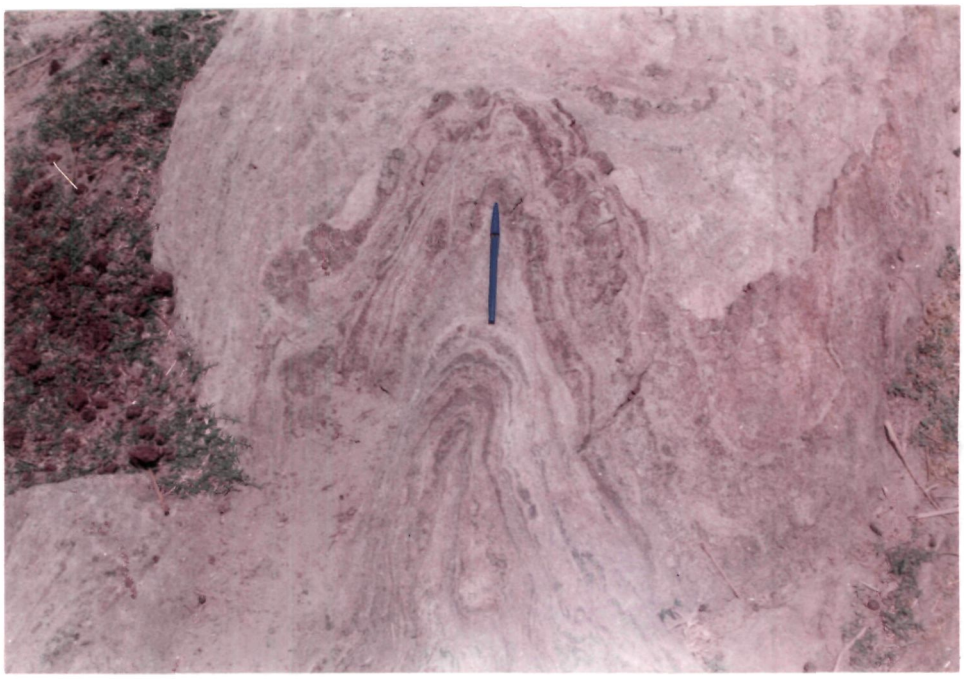
a) Field photograph showing the folds of second deformational episode (D2).

b) Field photograph showing the isoclinal folds of second deformational episode (D2).

PLATE 2



(a)



(b)

accompanied by gently inclined discrete, crenulation cleavage parallel to their axial planes (plate-3a). Most of the D2 folds occur on the limbs of large upright folds of second generation and vary in geometry from round hinged folds to kink bands and conjugate folds.

The third phase of deformation has effected the planar and linear structures of the area. The D3 folds are of low amplitude/wavelength ratio (plate-3b)and vary in shape from sharp hinged to round hinged (plate-4a).

Structural Control of Sulphide Ores

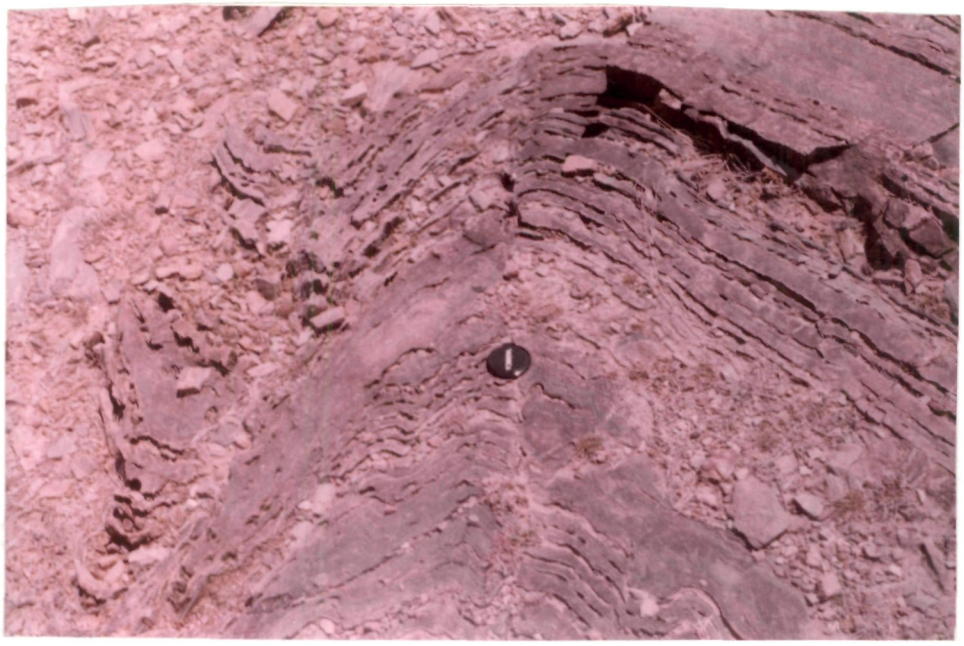
The sulphide ores are primarily controlled by certain structural features like shear zones, foliation planes and axial regions of microfolds in the lower marble of Sawar Group. Ray (1986) has carried out detailed studies on the structural control of sulphide ores and has stated that the third (D3) episode of deformation of the rocks of Sawar Group had created certain openings which were filled up by the ore minerals and the associated siliceous gangue. During the D3 deformation, the D2 folds were flattened by a component of the compressional force, acting normal to their axial surface. These flattening produced zones are of low pressure at the D2 hinges, where the saddle reef ore bodies were emplaced.

Plate 3

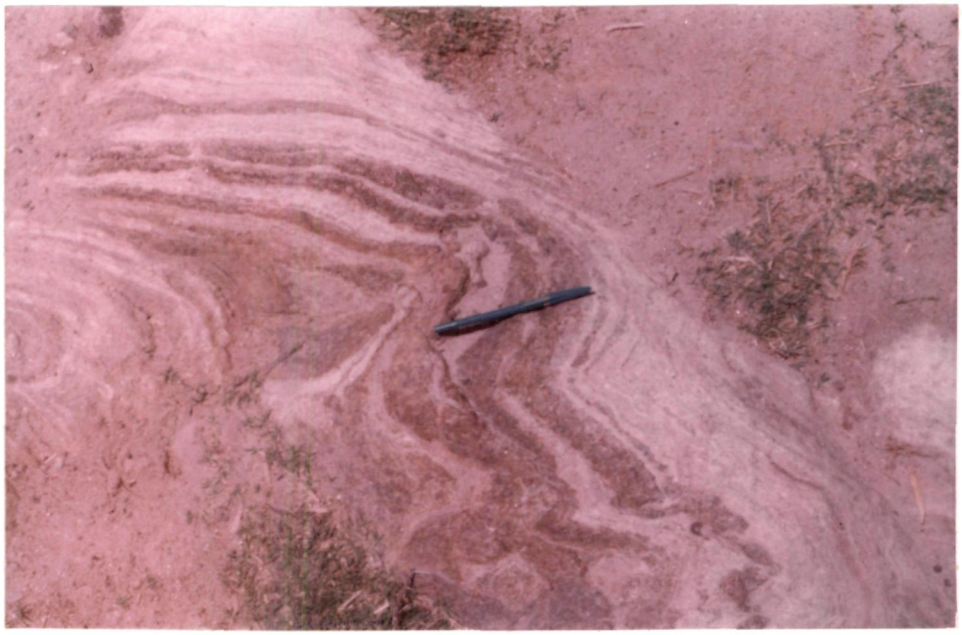
a) Field photograph showing the crenulation cleavage of second generation in the upper marble of the Sawar Group.

b) Field photograph showing the variation in the hinge of the fold from sharp to rounded.

PLATE 3



(a)



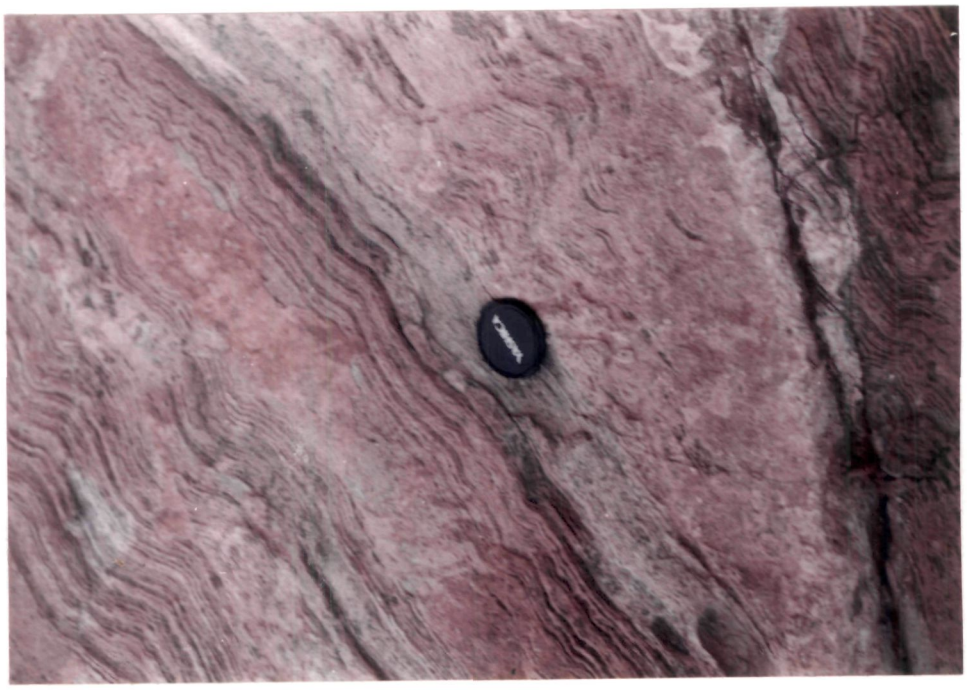
(b)

Plate 4

a) Field photograph showing the folds of low amplitude/wavelength ratio of third generation in upper schist of the Sawar Group.

b) Field photograph showing the Sawar fort in the Sawar village of Ajmer District.

PLATE 4



(a)

(b)

CHAPTER - 4

PETROGRAPHY OF THE COUNTRY ROCKS

PETROGRAPHY OF THE COUNTRY ROCKS

The lower marble of sawar Group is the host rock for base metal mineralisation. Based on the detailed petrographic studies of 80 thin sections, their textures and mineral assemblages, the lower marble may be classified as siliceous marble and impure marble.

Siliceous Marble :

The siliceous marble which forms the host rock for the base metal mineralisation is composed of calcite, silica, dolomite, biotite, muscovite, chlorite, sericite, foldspar, hornblende, diopside, tremolite forsterite and epidote. But silica is the mineral of most common occurrence. The recrystallization of calcite and quartz are very common in siliceous marble. The general texture of the rocks is entirely destroyed.

Impure Marble :

The Impure marble of the lower marble of Sawar Group also forms the host rock for the base metal mineralisation. Impure marble in addition to calcite, diopside, hornblende and tremolite contains dolomite,biotite, muscovite, chlorite, sericite, silica, feldspars, forsterite and epidote.

Mineralogy of the Country Rock

Calcite:

Calcite is the most dominant mineral in the lower marble of Sawar Group. The medium to coarse grained crystals are common but, euhedral varieties have also been identified showing a triple point junction. The calcite crystals exhibit rhombohedral cleavage (plate 5a). Twin lamellae are mostly parallel to the long axis of rhombohedran. The two generations of calcite have been observed. First generation calcite is replaced by quartz (plate 5a), diopside, tremolite (plate 5b) and hornblende (plate 6a).The deformational twinning shown by calcite crystals (plate 5b) of fine grained quartz also enclosed with the calcite (plate 5a) showing the second generation of calcite .

Dolomite :

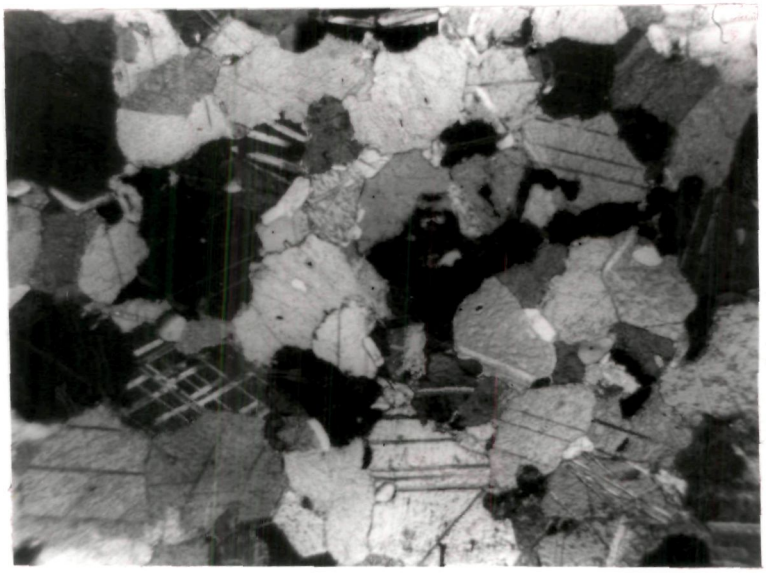
Dolomite has also been identified. The medium to coarse grained, subhedral to euhedral crystals of dolomite are common. It shows polysynthetic twinning. The twinning lamellae are Parallel to the short and long axis of rhombohedron (plate 6b).

Plate 5

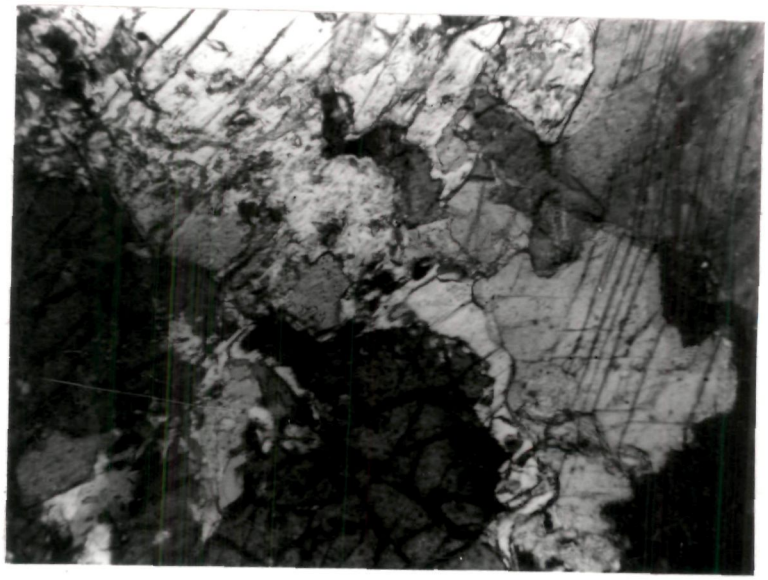
a) Microphotograph showing the rhombohedral cleavage in calcite and is also replaced by quartz (+Nic., 150 X).

b) Microphotograph showing calcite of first generation, replaced by tremolite, muscovite is also seen (+Nic., 300 X).

PLATE 5



(a)



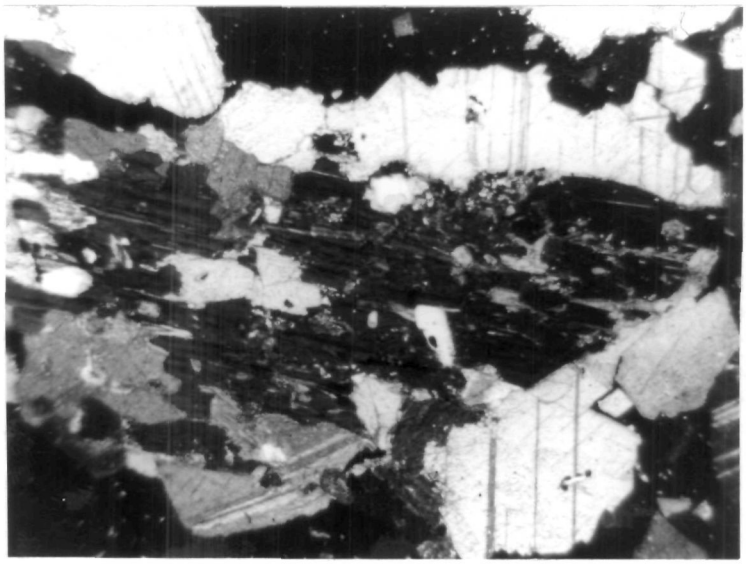
(b)

Plate 6

a) Microphotograph showing calcite of first generation replaced by hornblende (+Nic., 150 X)

b) Microphotograph of dolomite showing twinning, parallel to the short and long axis of rhombohedron (+Nic., 150 X).

PLATE 6



(a)

(b)

Quartz :

The quartz is the most ubiquitous mineral observed in the rocks of lower marble. It is colour less and occurs in four different generations. On the basis of paragenetic relationship and petrographic characters, they have been designated as quartz-I, quartz-II, quartz-III and quartz-IV in the order of descending antiquity.

Quartz-I:

Quartz-I grains occur as equant grains with sutured contacts (plate 7a). The grain exhibit clear boundary outline which represent the metamorphic realm. The signature of the metemorphic realm is expressed as suture contacts which has obliterated the clastic boundary outline in the individual grains. The sum of the quartz grains are characterised by dusty inclusions and at places, the muscovite flakes are randomly oriented in the quartz-I. The quartz-I exhibits strain shadows and wavy extinction. The original clastic boundary can be delineated in quartz-I by the pattern of clusty incluson which exhibits intragranular recrystallization during the regional matamorphism.

Quartz-II:

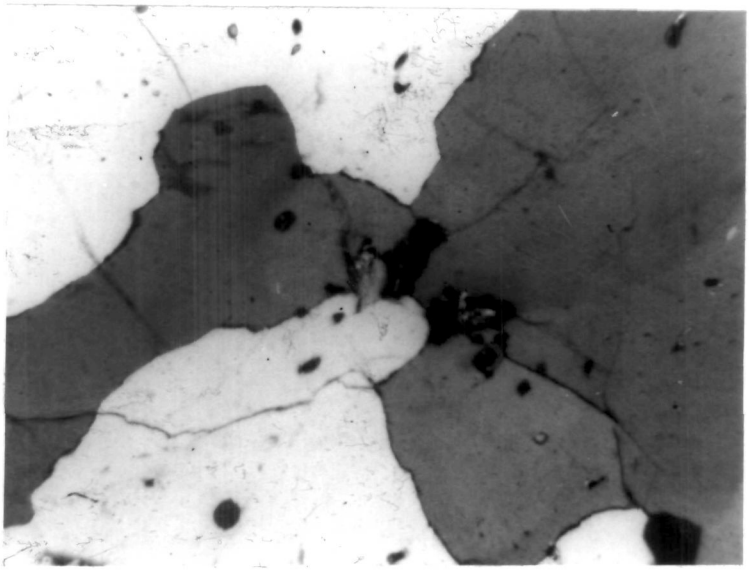
The quartz-II grains are recrystallized and are elongated and alligned parallel to the regional foliation (S2) (plate 7b). The quartz-II grains exhibit

Plate 7

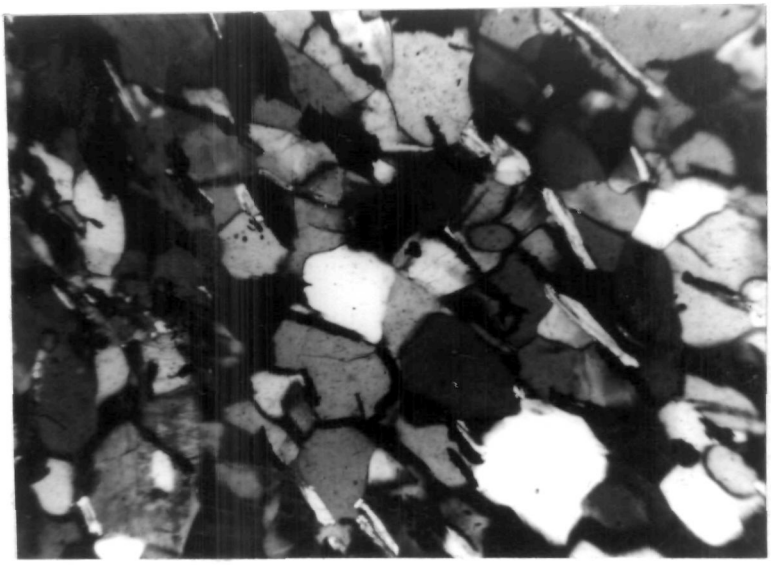
a) Microphotograph showing quartz - I grains with sutured contacts (+Nic., 150 X).

b) Microphotograph showing quartz - II grains with elongated and linear contacts. Sericite is also aligned parallel to the quartz grains (+Nic., 300 X).

PLATE 7



(a)



(b)

Plate 8

a) Microphotograph of quartz - II grains, exhibiting triple point junction (+Nic.,150 X).

b) Microphotograph showing veinlets of quartz-IV as fracture filling (+Niv., 150 X).

elongated and linear contacts with the adjacent mineral assemblages. The quartz-II grains exhibit undulose extinction and strain shadows and they also exhibit triple point junction (plate 8a).

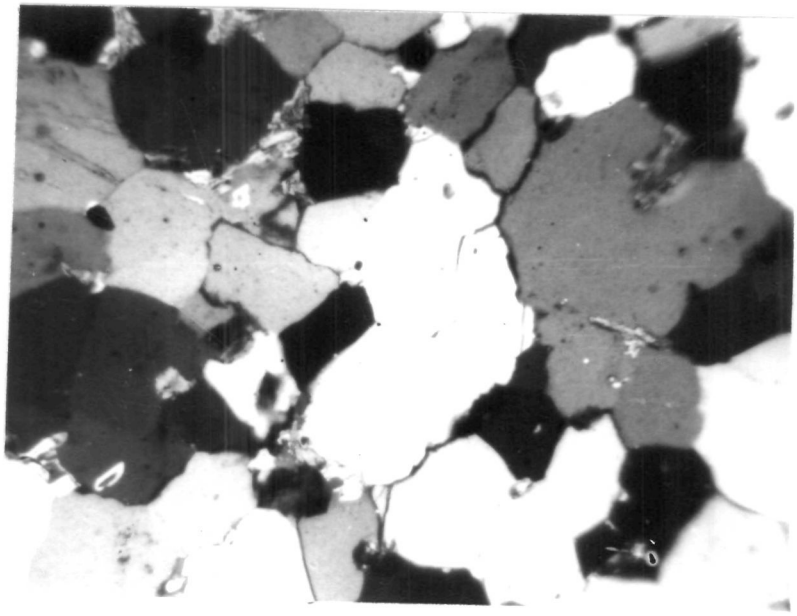
Quartz-III :

Quartz-III grains occur as inclusions within the mosaic of dolomite, calcite, muscovite and biotite (plate 5a). They are anhedral and generally free from strain effects which possibly suggest post tectonic origin. The quartz-III grains' boundaries are anhedral which probably indicate the released mineral in the paragenetic evolution of mineralogic population.

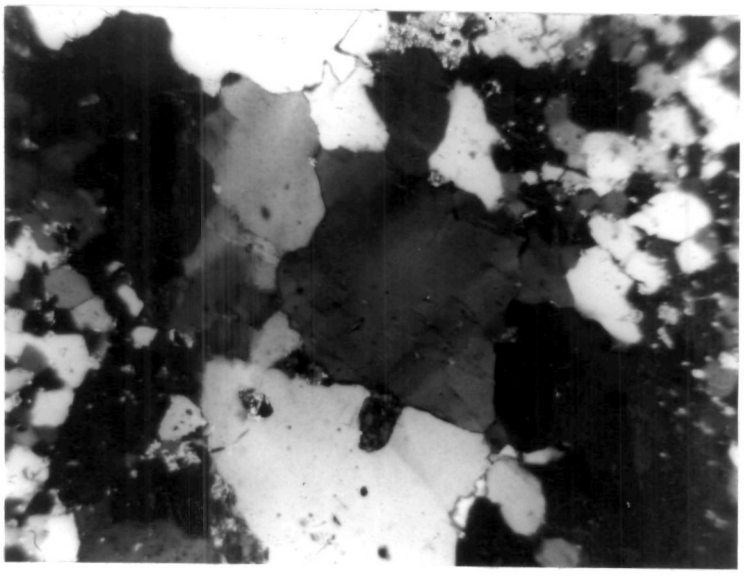
Quartz-IV:

The quartz-IV grains are observed in the lower marble of Sawar Group where the veinlets of quartz are seen as fracture filling (plate-8b) which possibly suggest youngest quartz grains in the ascending order of antiquity. These fractures have been heeled up by the recrystallized quartz-IV in the form of veinlets showing anhedral mosaic of quartz grains which are slightly strained as seen from the wavy extinction in the quartz-IV grains represent possibly the last phase of the recrystallization history in the metasedimentary sequence of Sawar Group of Bhilwara Supergroup.

PLATE 8



(a)



(b)

Diopside :

Diopside is a very common mineral in the lower marble of the Sawar Group. It exhibits pale green to bright green colour. Subhedral crystals of short prismatic habit, from medium to coarse grained are common. Diopside shows two sets of cleavage at right angles to each other. Diopside is replacing to dolomite and replaced by hornblende (plate 9a).

Tremolite :

Tremolite is very commonly identified in the lower marble of the Sawar Group. Tremolites of long prismatic forms are very common. Tremolite is replacing to cacite (plate 5b).

Hornblende:

Hornblende is also a common mineral in the lower marble of the Sawar Group. The medium to coarse grained crystals of hornblende occur as prismatic and pseudohexagonal form. It exhibits strong pleochroism in shades of light blue. Hornblende is replacing to diopside and calcite (plate 6a).

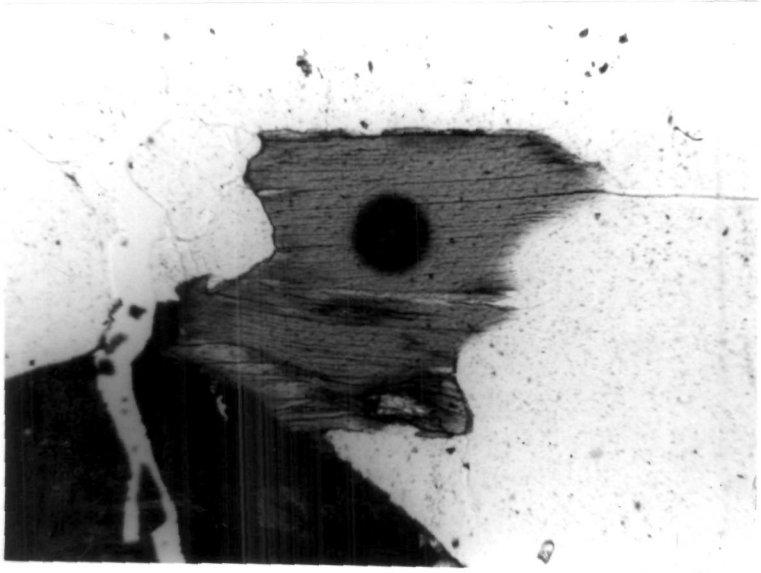
Plate 9

Microphotograph showing dolomite which is replaced by diopside and diopside is replaced by hornblende (+Nic., 150 X).

Microphotograph showing pleochroic halos of radioactive minerals in biotite (300 X).

PLATE 9

(a)



(b)

Muscovite:

The medium to coarse grained crystals of muscovite occur in the form of sheet, having flaky habit. The grains exhibit to low relief and have preferred orientation along the regional foliation. The muscovite occurs in close association with calcite, sericite and biotite.

Biotite:

Biotite occurs as crystals of lamellar habits. It is dark brown to greenish brown in colour showing strong pleochroism. The biotite is also showing pleochroic halos of radioactive minerals (plate 9b). The biotite flakes are referrable to two generations of growth. The first generation of biotite occurs as large lamellar grains defining the tectonic anisotropy. The second generation of biotite devoloped as veinlets along the tensional gashes has been observed (plate 10a). The biotite occurs as anisotropically oriented flakes. The boundary outlines are anhedral against the projected ends of quartz, diopside, calcite, pyroxenes and amphiboles.

Sericite:

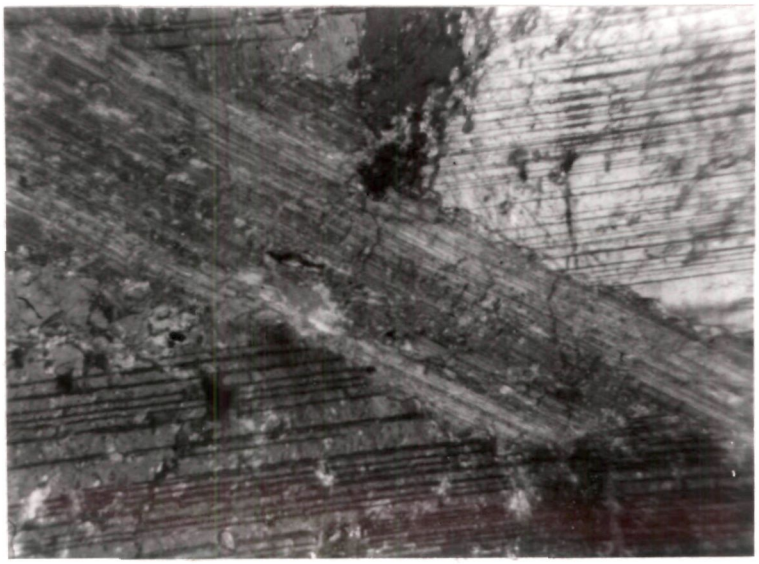
Sericite occurs as minute shreds exhibiting preferred orientation, parallel to the regional foliation (plate 7b). It is present in close association with quartz.

Plate 10

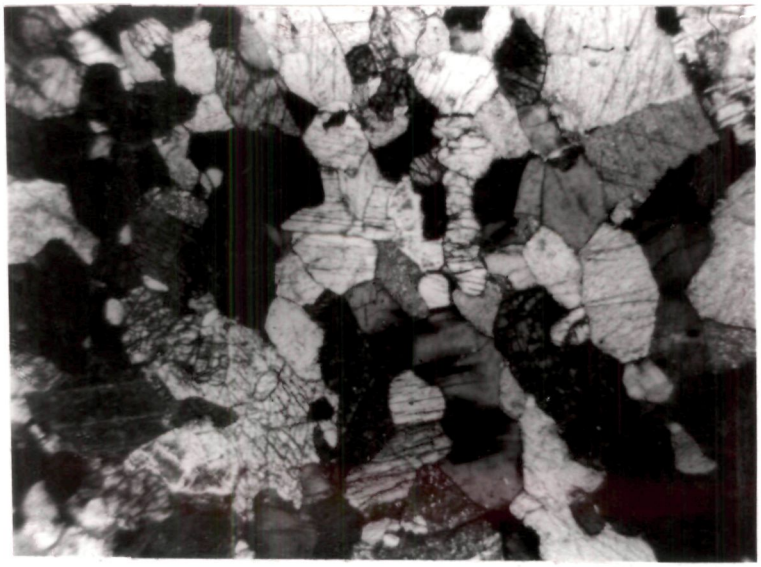
a) Microphotograph showing biotite of two generation inclined to each other. Biotite is also replaced by chlorite (+Nic., 150 X).

b) Microphotograph showing epidote in association with hornblende, calcite and quartz (+Nic.,150X).

PLATE 10



(a)



(b)

Chlorite:

The chlorite is present as prismatic porphysroblast which is pale green in colour and exibits pleochroism and shades of green. Chlorite is replacing to biotite (plate 10a).

Epidote:

Epidote occurs as discrete idioblastic grains, exhibiting faint pleochroism in shades of green. It is characterized by high refractive index and its varigated interference colour. It occurs in association with hornblende, calcite and quartz (plate 10b).

Apatite:

The grains of apatite exhibit prismatic habit and high refractive index.

Feldspar:

Feldspar grains vary in size from medium to coarse. Most of the feldspars are of microcline type showing chessboard twinning (plate 11a) but, plagioclase is also present in abundance in the form of small

Plate 11

a) Microphotograph of microcline, showing twinning of chessboard type (+Nic., 150 X).

b) Microphotograph showing pyrite I in pyrrhotite I as inclusions and pyrrhotite-I is replaced by chalcopyrite-I along grain boundary (240 X).

PLATE 11

(a)

(b)

phenocrysts. The boundary lines are euhedral against the muscovite flakes and calcite which occurs in close juxtaposition with the plagioclase phenocrysts. Also, there are few inclusions of quartz in plagioclase.

Forsterite:

Forsterite occurs as wel formed crystals. Curving cracks frequently cut the grains in various directions. The most characterstic feature of forsterite is its high relief and lack of well developed cleavage.

WALL ROCK ALTERATION

Alteration type :

The most prominent features, indicative of rock alteration, in the vicinity of sulphide ore body at Sawar-Bajta area are bleaching, softening and yellow or brown discoloration of the country rocks. The yellow or brown colour is due to the hydrous iron oxides originating as a result of pyrite and biotite. The effect of bleaching is a result of sericitization. The major alteration types that can be recognised at Sawar-Bajta area are:

1. Sericitization
2. Argillization
3. Silicification

Sericite-argillic alteration is the general term applied here to the assemblages containing sericite, quartz feldspars and sulphides. Sericite argillic assemblages are the products of moderate to strong hydrolytic alteration (Hemley and Jones, 1964).

Sericite-argillic alteration

All the alteration assemblages in the study area show a considerable amount of overlapping. The coexitence of sericite and secondary quartz indicates simultaneous sericitic and argillic alteration and silicification (plate-8b). It can be visualised that as long as active circulation of hydrothermal fluids continued along the vein, each zone migrated away from the fissures, that is, it grew outer edge and simultaneously receded at its veinwards edge because of encroachement by the next inner zone. This alteration type predates the main stage of sulphide mineralisation, since most of the minerals of this assemblage are replaced by the sulphide minerals.

1. Zone of Sericitization

Zone of sericitization is characterized by the predominence of white mica or sericite and secondary quartz (plate-7b). All the metamorphic minerals and some quartz are replaced by the secondary assemblages. The feldspars are completely obliterated at places, adjoining the sulphur ore body.

2. Zone of Argillization

In the zone of argillization, the sericitization is less intense (plate-11a) however, in sericite zones the alteration is more intense (plate-8b) whereas, towards the outer fringe, they have generally survived the complete alteration.

3. Zone of Silicification

The zone of silicification shows a marked decrease in sericitization. In this zone the plagioclase and biotite appear much less altered than in the zone of argillization. Secondary silica is much abundant in this zone (plate-8a).

The secondary quartz replaces metamorphic quartz and feldspars along the grain boundaries. Secondary and hydrothermal plagioclase form a significant part of the assemblage. Hydrothermal plagioclase occurs as irregular poikloblasts, containing inclusions of quartz and other micaceous minerals. The altration of calcite into quartz has commonly been observed in the zone of silicification (plate-5a).

CHAPTER - 5

TYPES & MINERALOGY OF THE ORES AND THEIR METAMORPHISM

TYPES AND MINERALOGY OF THE ORES AND THEIR METAMORPHISM

The Sawar-Bajta belt is known for its base metal deposits which are associated with the lower marbles of the Sawar Group. An attempt has been made to classify and to present a morphological description of each of the ore type.

The base metal deposits are of disseminated type, distributed in the host rocks in the form small specks, blebs and small veinlets.

Mineralogy

Eleven ore minerals have been identified, in the polished sulphide ores of the study area with the help of ore microscopy,which are Pyrite, pyrrhotite, chalcopyrite, galena, sphalerite, cubanite, marcasite, goethite, delafosite, cuprite and cerussite.

Pyrite (FeS2) :

Pyrite is generally found as disseminated grains and crystals in association with Pyrrhotite, sphalerite, galena, chalcopyrite and marcasite within the lower marble. They are slightly elongated along the laminations,

probably due to the compression during lithification. Two generations of pyrite have been observed under the microscope and have been designated as pyrite-I and pyrite-II.

Pyrite-I :

Euhedral to subhedral grains appear as individuals or crystal clusters. It often occurs in association with pyrrhotite as inclusions (plate-11b). It also occurs with chalcopyrite, sphalerite, galena and marcasite. This pyrite is replaced by pyrrhotite (plate-11b), marcasite (plate-12a) and sphalerite (plate-12b). First generation pyrite is readily recognised by the abundance of inclusions.

Pyrite-II :

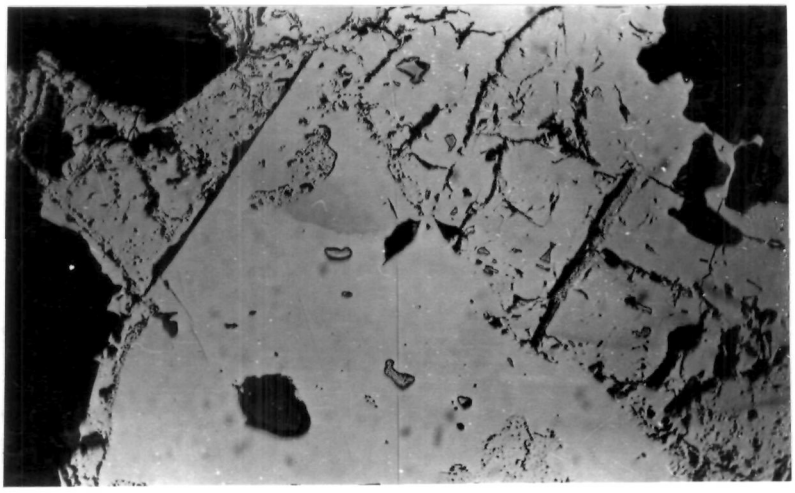
This pyrite is coarse grained. It appears as well developed porphyroblasts. It is more euhedral in form and contains less inclusions (plate-13a). This pyrite appears as individuals or clusters and is free from inclusions of pyrite I. It usually contains inclusions of marble and Pyrrhotite-I (plate-13b)and sphalerite of first generation (plate-14a). Second generation pyrite is more common than the earlier type and they are coarser in comparision with the first generation.

Plate 12

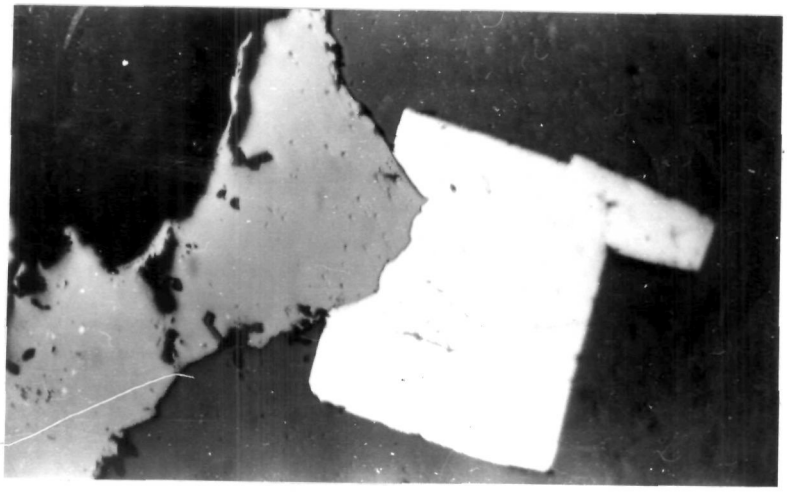
a) Microphotograph showing pyrite-I replaced by marcasite and pyrrhotite along grain boundary (240 X).

b) Microphotograph showing pyrite-I replaced by sphalerite-I along grain boundary (240 X).

PLATE 12



(a)



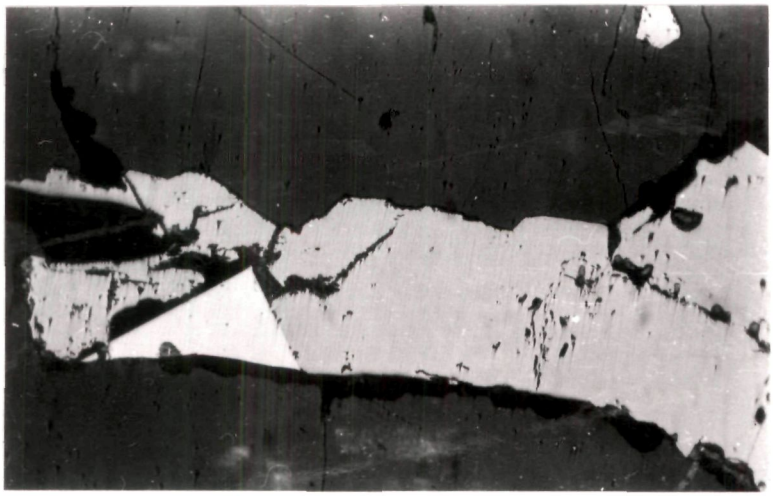
(b)

Plate 13

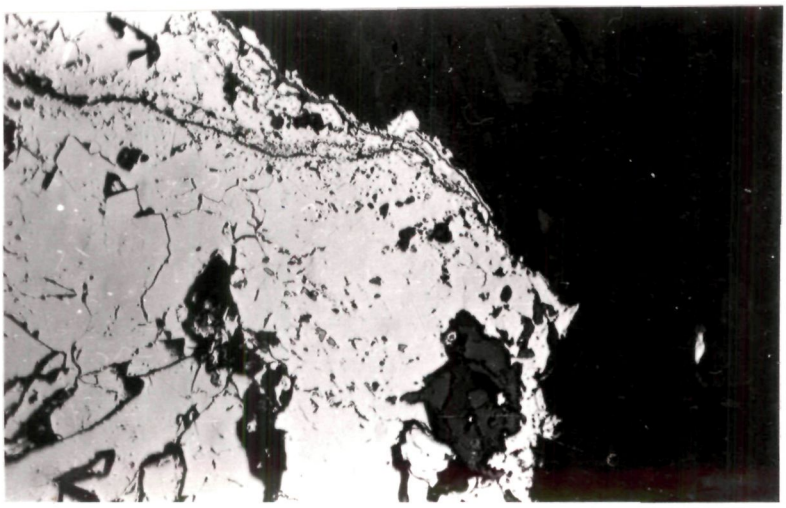
a) Microphotograph showing idioblastic pyrite-II replacing to pyrrhotite-I (240 X).

b) Microphotograph showing pyrite-I containing inclusions of marbles and pyrrhotite-I (240 X).

PLATE 13



(a)



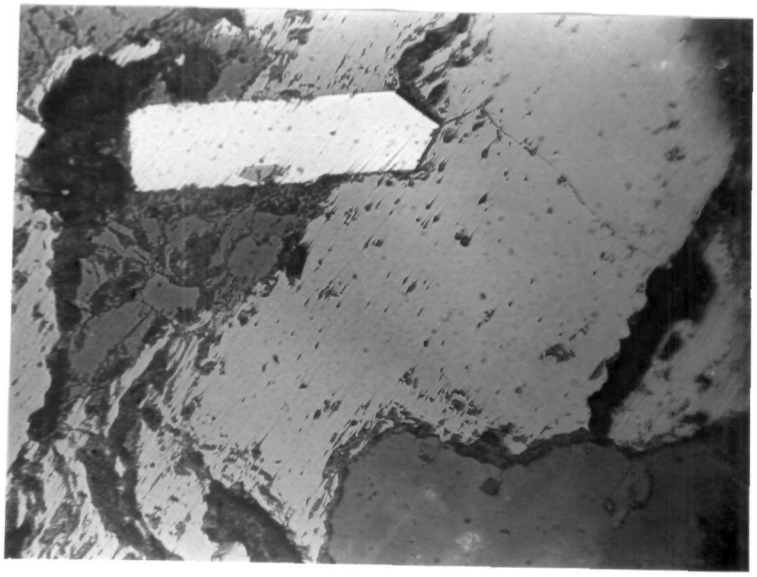
(b)

Plate 14

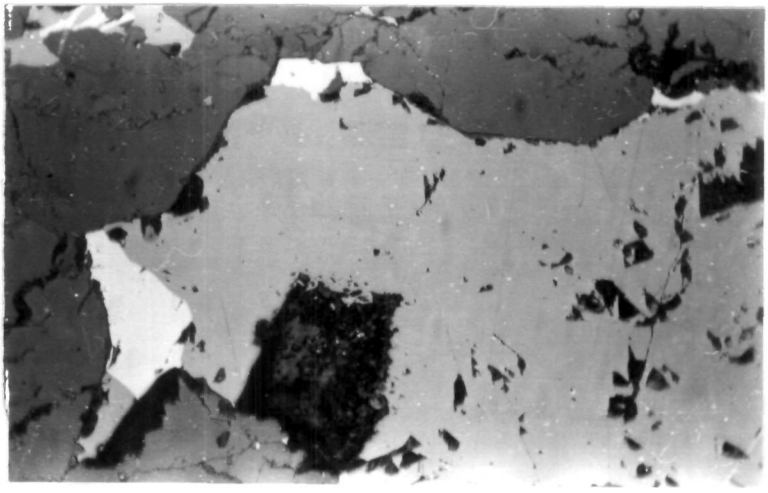
a) Microphotograph showing pyrite-II replacing to sphalerite-I and sphalerite-II (240 X).

b) Microphotograph showing exsolution of sphalerite and pyrrhotite (240 X).

PLATE 14



(a)



(b)

Pyrrhotite (SFeS):

Two generations of pyrrhotite is observed under the microscope and have been designated as pyrrhotite-I and pyrrhotite-II. Pyrrhotite is a dominant sulphide in the remobilised and tectonoclastic ores. Corroded relict pyrite occurs within pyrrhotite. Exsolution of sphalerite with pyrrhotite has also been observed (plate-14b).

Pyrrhotite-I:

It occurs as pseudomorphic grains or clusters replacing marble and as inclusion in pyrite-II (plate-13b). The tiny pyrrhotite grains occur as individuals or clusters, fairly and widely distributed in marble. Their size, crystal forms and distribution are almost identical to those of pyrite-I and there seems to be little doubt that these pyrrhotite grains are pseudomorph of pyrite-I. They have been originated through the loss of sulphur from the pyrite. Pyrrhotite-I is also replaced by galena-I, chalcopyrite-I (plate-15a) and sphalerite-I (plate-15b),.

Pyrrhotite-II :

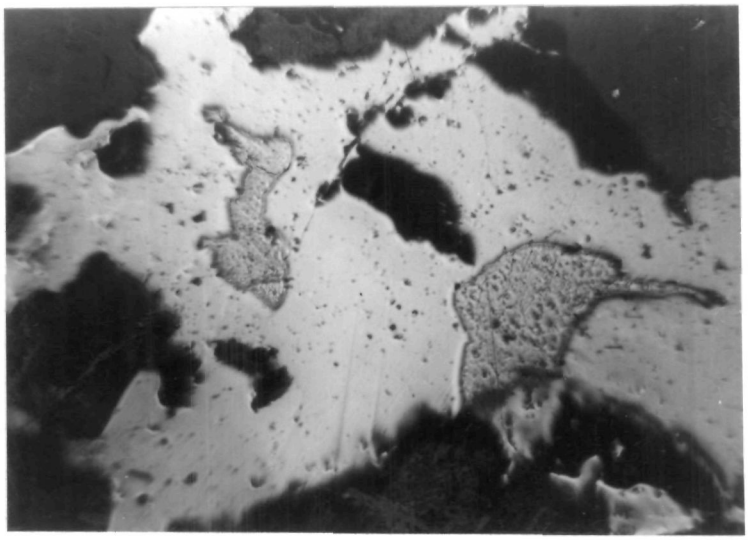
Pyrrhotite-II in the deposit, is coarse grained, resulting from the replacement of marble. Pyrrhotite-II is replacing to chalcopyrite-I (plate-15a) and sphalerite-I (plate-15b).

Plate 15

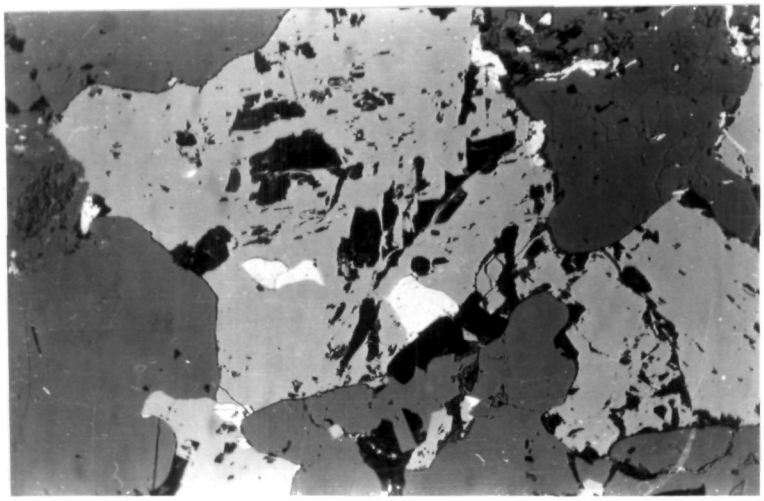
a) Microphotograph of pyrrhotite-I replaced by galena-I, chalcopyrite-I and chalcopyrite-I replaced by pyrrhotite-II (120 X).

b) Microphotograph showing pyrrhotite-II which is replacing to sphalerite-I and chalcopyrite-I (240 X).

PLATE 15



(a)



(b)

Sphalerite (ZnS):

Sphalerite occurs in the form of discrete or subhedral grains and in most cases found in association with galena and chalcopyrite and occurs less commonly with pyrite and pyrrhotite. Exsolution of sphalerite with chalcopyrite is very common (plate-16a). Exsolution of sphalerite with pyrrhotite is also observed (plate-14b). Sphalerite of two generations has also been observed under the microscope and has been designated as sphalerite-I and sphalerite-II.

Sphalerite-I :

It is light grey in colour and exhibits internal reflection of orange colour. It occurs in single grain or in clusters. Sphalerite-I is replacing to pyrrhotite-I (plate-16b). Sphalerite-I is replaced by pyrite-II (plate-14a) and pyrrhotite-II (plate-17a).

Sphalerite-II :

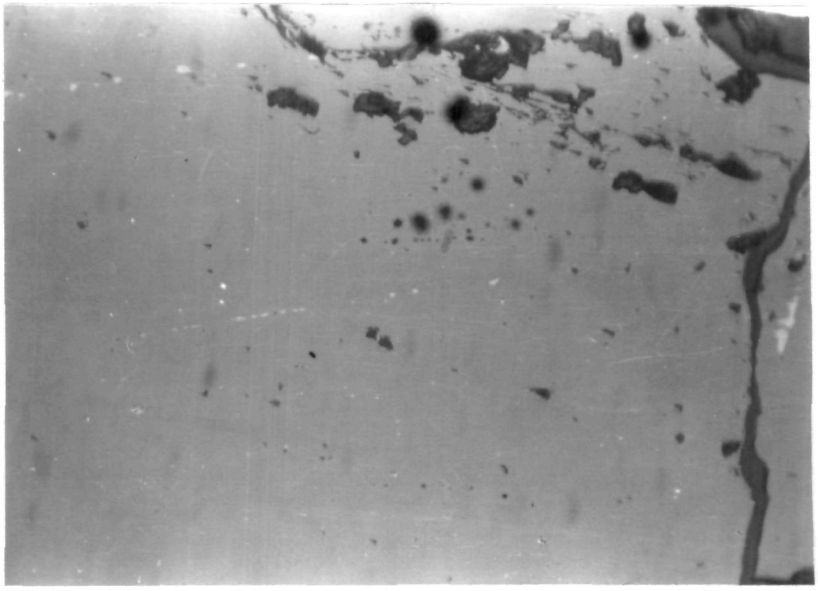
It is dark grey in colour and exhibits red coloured internal reflection. Sphlerite-II is replacing to chalcopyrite-I (plate-17b) and galena-I (plate-18a).

Plate 16

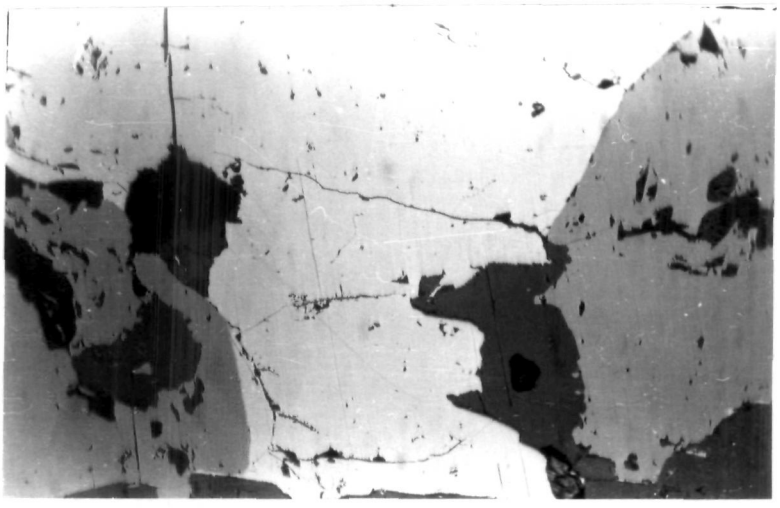
a) Microphotograph showing exsolution texture of sphalerite with chalcopyrite (240 X).

b) Microphotograph of sphalerite-I replacing to pyrrhotite-I (240 X).

PLATE 16



(a)



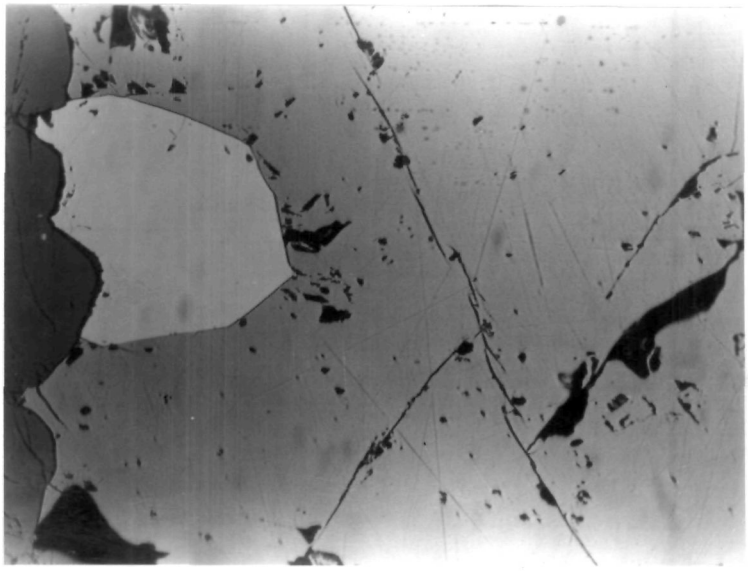
(b)

Plate 17

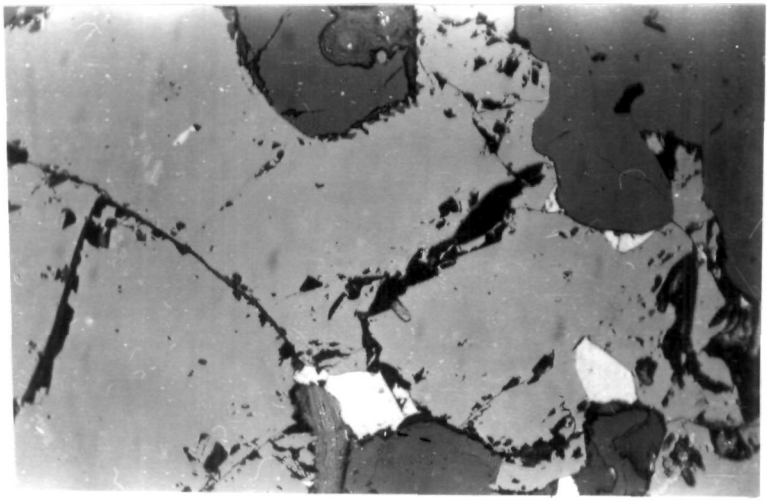
a) Microphotograph of sphalerite-I replaced by pyrrhotite-II (240 X).

b) Microphotograph of sphalerite-II replacing to chalcopyrite-I and chalcopyrite-II replacing to sphalerite-I (240 X).

PLATE 17



(a)



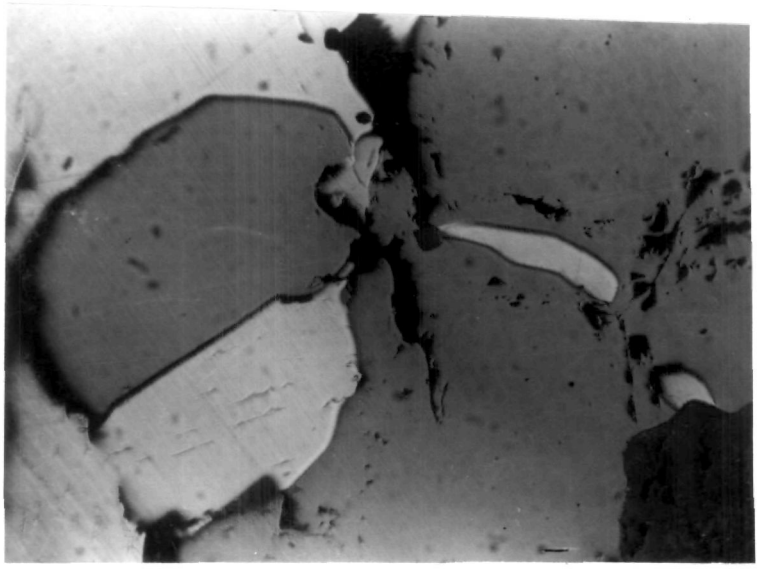
(b)

Plate 18

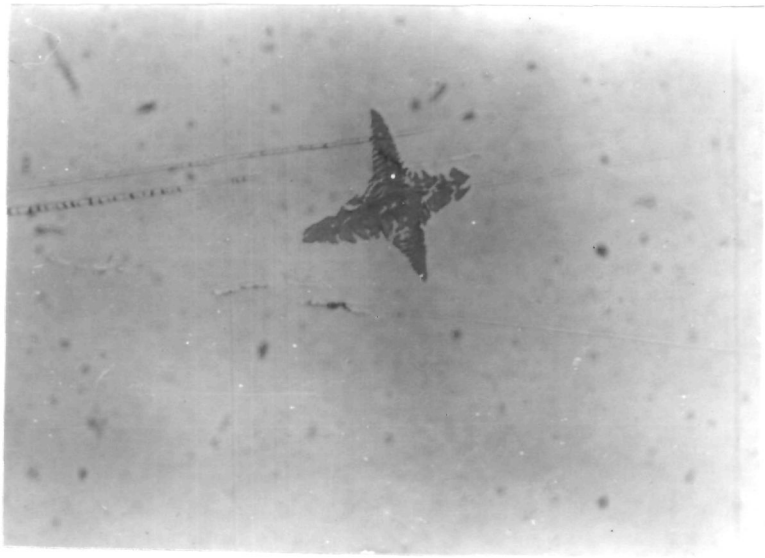
a) Microphotograph of sphalerite-I replacing to galena-II (120 X).

b) Microphotograph showing exsolution texture of chalcopyrite with sphalerite in the form of sphalerite star (1200 X).

PLATE 18



(a)



(b)

Chalcopyrite :

Chalcopyrite occurs as aggregates of granules. Sphalerite forms exsolution with chalcopyrite showing the sphalerite star (plate-18b). It also forms the exsolution with the cubanite in the form of cubanite lamellae (plate-19a). Chalcopyrite of two generations has been observed under the microscope and has been designated as chalcopyrite-I and chalcopyrite-II.

Chalcopyrite-I :

Anhedral to subhedral crystals of chalcopyrite are common. Chalcopyrite-I is replacing to pyrrhotite-I (plate-15a) and Sphalerite-I (plate-17b)and contains extensive twinning.

Chalcopyrite-II :

Chalcopyrite-II is very common and replacing to sphalerite-II (plate-17b).

Cubanite (CuFe2S3):

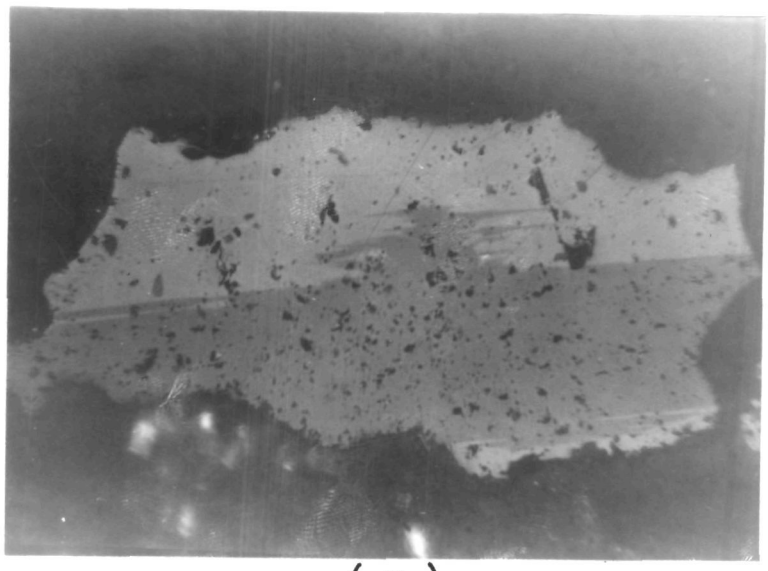
Cubanite occurs as lamellar or lath shaped within the chalcopyrite (plate-19a). The cubanite lemellae are the exsolved products of chalcopyrite. The length of the lamellae varies while occurring in the twinned composite

Plate 19

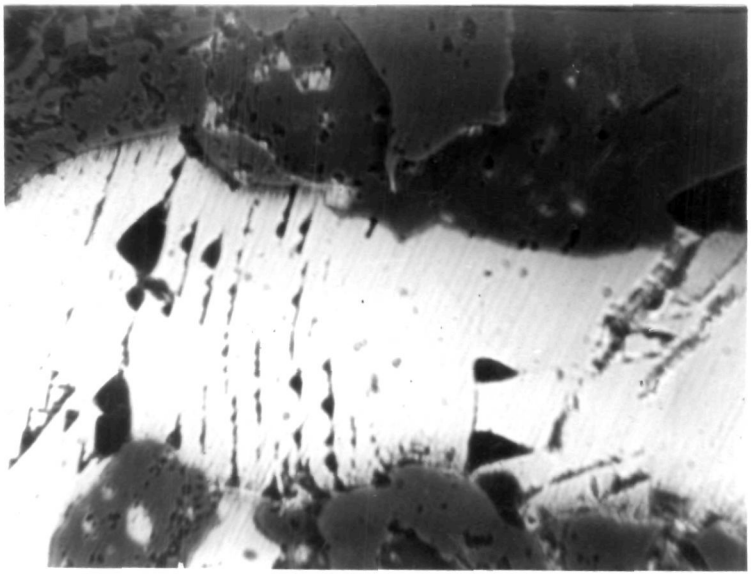
a) Microphotograph showing exsolution texture of chalcopyrite with cubanite in the form of cubanite lemellae (300 X).

b) Galena showing characteristic triangular Pits (150 X).

PLATE 19



(a)



(b)

form and the chalcopyrite lamellae alternate with those of cubanite. Most of the exsolved lamellar cubanite might have resulted from the reversal of high chalcopyrite to low chalcopyrite on cooling (Buergar and Buerger, 1934).

Galena (PbS):

Galena occurs as subhedral to anhedral crystalline masses characterized by cleavage, visible as triangular pits in polished section (plate-19b). The deformation studies on galena (Solman et.al., 1974 and Clark et.al., 1977) have shown that it is the most ductile of the common sulphides. Thus, it will generally undergo remobilisation to be concentrated in zones of lower pressure and can flow plastically into fractures and openings. Galena is commonly found associated with sphalerite about which it may form a network or itself make up the grains in a network of galena (plate-20a).

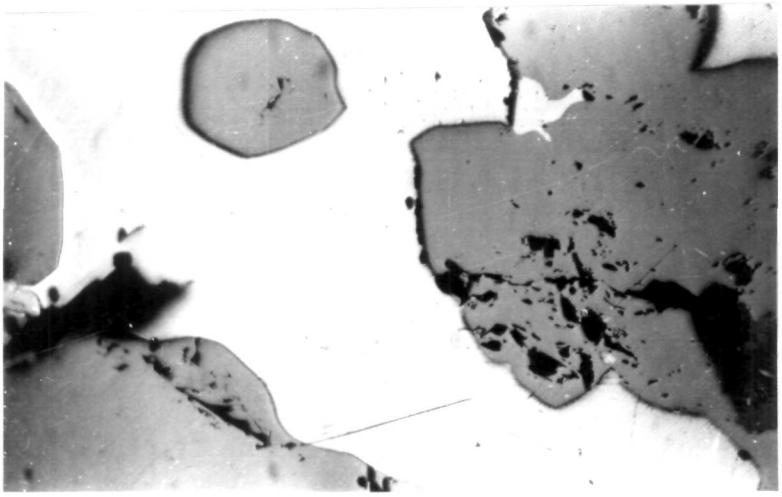
The inclusions of sphalerite in galena are commonly rounded and corroded (plate-20a), which is interpreted as being suggestive of the replacement of sphalerite by galena. There are two generations of galena in the area.

Plate 20

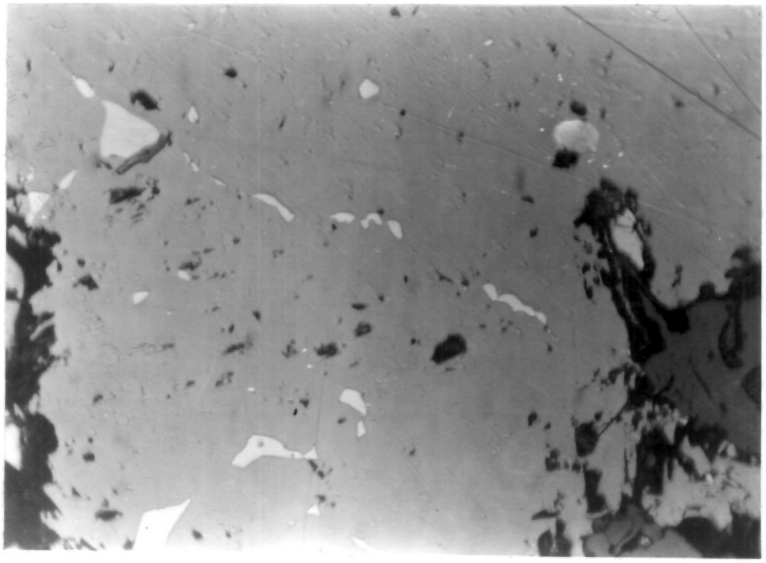
a) Sphalerite replaced by galena (240 X).

b) Exsolution texture of sphalerite with chalcopyrite (240 X).

PLATE 20



(a)



(b)

Marcasite(FeS2) :

The fine grained aggregates of marcasite replacing the pyrite along the grain boundaries have been observed (plate-12a). Since marcasite is rare in the metamorphosed sulphide deposits and inversion to pyrite normally takes place during the metamorphism. Therefore, this marcasite might be a post metamorphic replacement phenomenon .

Delafossite (CuFe2O):

Delafossite has been observed in disseminated form, fine to medium grained often bundles of fibres.

Goethite (Fe2O3. H2O):

The brownish coloured goethite having needle like crystals has been observed frequently under the microscope. It is also exhibiting in many cases, as beautiful, rhythmically alternating, concentric shells, which are visible perhaps, due to the slight variation in grain size or polishing properties.

Cerussite (PbCo3):

Cerussite forms most often as a weathering product of galena. The cleavage of galena is preserved as a relict texture in the cerussite.

Cuprite (Cu2O):

Cuprite is commonly the formation of the oxidation zone of cu-rich deposits. It occurs in the form of granular or skeleton like aggregates.

Metamorphism

General Statement :

Metamorphism of the sulphide ores and their host rocks is presumably interrelated and the ores generally fallow the same common laws of matemorphism as those of host rocks. This has been demonstrated by the metamorphosed sulphide deposits from different geological ages from, Precambrian to Tartiary (Vokes, 1969). The idea of metamorphism of Precambrian sulphide deposits, which was first introduced by Carstens, (1931) and has been accepted by the majority of the later investigators (Ramdohr, 1953 a; Domarev, 1956; Mc Donald, 1967; Stanton; and Gorman, 1968; Stanton, 1972; Mookherjee, A,1976).

An attempt has been made to identify the possible type of metamorphism of the ores, essentially based upon their textural features, mineral assemblages, paragenesis and to describe briefly the trend of their metamorphism.

Texture

Four distinct types of ore texture were identified under reflected light, which are replacement, exsolution, annealing and deformation.

Replacement Textures:

The replacement textures are evident along grain boundaries, cleavage planes and fractured spaces generally between the adjacent pairs of minerals. The conversion of pyrite to marcasite (plate 12a), and pyrite to pyrrhotite (plate 11b) is due to desulphurization of pyrite as a result of regional metamorphism (Harrison, 1950 Friedman, 1959, Gammon,1966). The convex margins of chalcopyrite are partly replaced by second generation of pyrrhotite (plate 15a). These mineralogical changes are supposed to be the characterstics of the dyanamothermal metamorphism related with the regional metamorphism (Mc Donald, 1967).

Exsolution texture:

Cubanite occurs as a platy mineral having single or complex lamellae along the plane (111) of chalcopyrite and this lamellar structures

suggests that cubanite exsolved directly into the orthorhombic form (Thole, 1976). The lamellar structures in cubanite are indicative of the effect of retrogressive metamorphism (plate 19a).

Chalcopyrite contains small inclusions of sphalerite in the form of dustlike, linear and especially star shaped particles (plate 18b) and are interpreted as the products of exsolution (Ramdohr, 1969). Chalcopyrite is embedded in sphalerite. Sometimes sphalerite contains minute ovoid grains of chalcopyrite (plate 16a). Sphalerite also contains tabular or lens-like forms of chalcopyrite embedded parallel to crystallographic direction (plate-16a and plate-20b). All these structures are indicative of exsolution (Ramdohr, 1969).

Sphalerite also contains minute ovoid grains of pyrrhotite (plate-14b). This structure is also indicative of pyrrhotite exsolution with sphalerite (Ramdohr, 1969). The deformation would promote exsolution of pyrrhotite with sphalerite. Barton and toulmin (1966) have observed that exsolution of pyrrhotite with sphalerite requires an addition of sulphur to the system.

Harrison (1950) observed that in Monitoba a change for pyrite rich to pyrrhotite rich ores is accompanied by an increase in intensity of regional metamorphism. Friedman (1959) and Gammon (1966) observed that during the regional metamorphism, pyrite is transformed to pyrrhotite. This may

explain why pyrite is less in comparision to pyrrhotite in Sawar-Bajta area, as these deposits occur in higher grade metamorphic rock.

Annealing texture:

The various processes by which the strain energy is released from deformed grains are known as annealing (Stanton and Gorman, 1968). The annealing texture has been identified by triple point junction, various twinning in chalcopyrite, subgrain formation and recrystallization. Annealing is generally accompanied by a regularization of grain slopes and an increase in grain size.

When the tapering of twin lamellae before the grain boundary is reached it is an indication of annealing twinning (Stanton, 1972). He also considered that those types of twinning were formed during thermal metamorphism. The subgrains are recognised from their different anisotropism and are mainly found in chalcopyrite and pyrrhotite showing annealing texture. In the present case, the grains of pyrite, and pyrrhotite have attained considrable size due to recrystallization and the formation of idioblastic pyrite in pyrrhotite (plate-13a) and may be taken as an evidence of dyanamic metamorphism (Ramdohr, 1969, Vokes, 1969).

Deformational Texture :

Chalcopyrite, pyrrhotite and pyrite are generally deformed in the direction of the schistosity of the host rock. The elongated pyrite grains do not show any well developed crystal faces unlike the idioblastic pyrites which are less deformed. Some example of elongated pyrite have been ascribed to syn to post crystallization deformation (Zavaritsky, 1950, Kanehira, 1959, Page, 1963 and Vokes, 1963). Sometimes folding, elongation and development of multiple radial fractures in pyrite are taken to be the effect of deformation (Mookherjee, 1971). The slow rate of strain is the possible reason of this type of deformational features (Graf, Jr. and Skinner, 1970). The possible explanation for the presence of chalcopyrite in the microfracture spaces of pyrite (plate-21) has been explained as due to the diffusion of the former in the later (Mookherjee 1971).

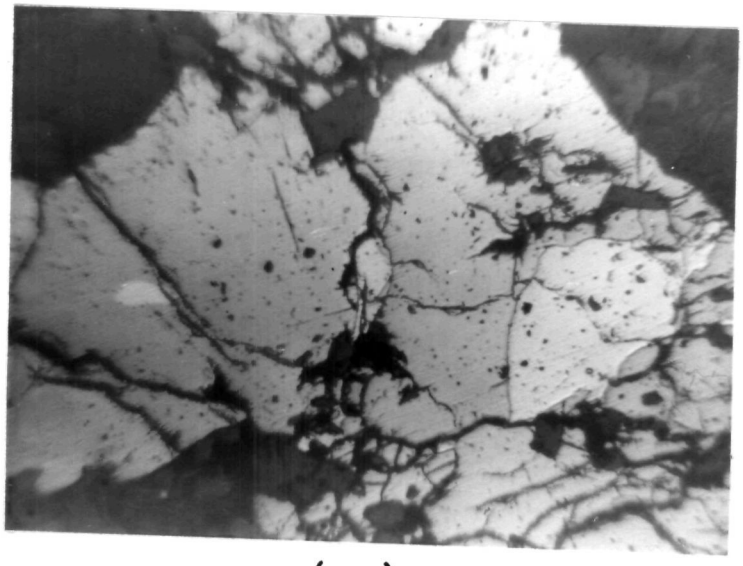
Temperature

The exsolution texture of certain ore minerals often provides some evidences for their possible temperature of formation. Cubanite is considered to be an accurate geothermometer for higher temperature, much FeS is soluble in chalcopyrite and the temperature at which unmixing of cubanite occurs was found to be in the range of 250-300°C (Ramdohr,

Plate 21

Microphotograph of pyrite containing chalcopyrite in the microfracture spaces (150 X).

PLATE 21



(a)

1969). The preservation of cubanite lamellae further suggests that the stress conditions were relatively stable since their formation.

A solution of chalcopyrite in sphalerite has been risen to a myriod of minute blebs or blades of chalcopyrite dispersed through the sphalerite and the chalcopyrite blebs are more or less distributed through the sphalerite, giving the so called emulsion or mottled texture (plate 16a). Exsolution intergrowth of sphalerite in chalcopyrite is also observed in which the sphalerite is devoloped as star shaped (plate-18b). Sphalerite and chalcopyrite are capable of some degree of solid solution at temperature above 350°C to 400°C and solution of chalcopyrite in sphalerite unmix at about these temperatures (Burger, 1935). Solution of chalcopyrite developes at rather higher temperature and unmixing occurs at about 550°C (Borchart 1934). In sum the exsolution textures and the mineral assemblages suggest that the temperature of mineralization of sulphide ores reached upto 550°C.

Paragenesis

Attempt has been made to present the paragenesis of the ore forming minerals on the basis of their assembleges and textural characteristic as follows.

Paragensis of Ores, Sawar-Bajta Area.

Minerals	Time →			
	Primary			Secondary
	Early		Late	
Pyrite	——		——	
Pyrrhotite	——		——	
Sphalerite	——		———	
Chalcopyrite	———		———	
Cubanite	——		——	
Galena	———		——	
Marcasite	——			
Delafossite				——
Goethite				——
Cerussite				——
Cuprite				——

CHAPTER - 6

GEOCHEMISTRY OF THE HOST ROCKS

GEOCHEMISTRY OF THE HOST ROCKS

The petrochemical nature of suite of host rocks associated with an ore body can usually be determined from unaltered or slightly altered rocks adjacent to or some distance away from the lode. But, the absence of unaltered rocks from the study area makes it virtually impossible to follow the restricted rules of geochemistry for investigating the original composition of the rocks. Nevertheless a possible identification of the original nature of the host rocks has been attempted based mainly on their chemical composition and behaviour. Metamorphism coupled with silicification and sericitization are the alteration processes which probably obliterated the original chemical nature of the parent rocks.

An attempt has been made to use the geochemical data particularly of the oxides of major elements for varifying the mineralogical composition of the host rocks.

The distribution of the major chemical constituents of the host rocks supports the above statement. Oxides of the major elements viz; SiO2, Al2O3, TiO2, Fe2O3, MgO, MnO and P2O5 are analysed on Parkin Elmer, uv/vis Spectrophtometer, (Modal : lamda 3B), CaO and MgO have been analysed by titration method, Na2O and K2O are analysed on EEL Flame Photometer and loss on ignition (LOI) is analysed by heating the powder sample on the glass tubes.

The results of the geochemical analysis of the major oxides of the host rock have been shown in table 2 and table 3.

Silica (SiO2):

Silica is moderately variable and shows a unimodal frequency trend.

Titania (TiO2):

Titania shows low variation with unimodal frequency distribution pattern.

Alumina (Al2O3):

Alumina being moderately concentrated in the marble, indicates as unimodal frequency trend.

Alkalies (Na2O and K2O):

Soda in marble shows a wide range of variation with unimodal characters. Potash also shows wide range a variation trend with unimodal characters.

Table.2 : Analytical results of major and trace elements of host rock of Sawar-Bajta area. (values in wt.%)

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SiO_2	16.99	18.74	21.44	19.14	19.82	19.32	16.69	17.17	18.75	17.39	16.25	14.11	17.04	19.85	20.79	19.27	21.4	21.26	20.2	20.3
TiO_2	0.2	0.08	0.23	0.21	0.23	0.29	0.19	0.26	0.09	0.08	0.19	0.14	0.17	0.21	0.23	0.16	0.15	0	0.19	0.16
Al_2O_3	8.51	7.32	6.12	7.96	7.36	7.51	6.87	6.85	5.93	7.11	8.69	8.32	8.55	8.16	7.5	7.31	7.32	6.29	7.82	5.6
Fe_2O_3	0.52	0.73	0.69	0.89	1.63	2.54	1.69	1.96	2.03	2.4	1.68	1.78	0.92	0.96	1.08	1.14	1.62	1.63	0.98	0.83
MnO	0.02	0.06	0.03	0.08	0.14	0.02	0.03	0.09	0.03	0.12	0.17	0.06	0.02	0.03	0.03	0.02	0.12	0.05	0.04	0.06
CaO	45.26	46.39	47.74	45.56	43.23	43.85	44.95	43.98	42.76	44.85	45.74	46.43	40.94	42.67	40.82	45.64	43.32	42.62	44.36	44.74
MgO	19.75	20.85	15.48	18.59	18.68	18.96	20.94	23.12	19.76	18.45	15.53	19.24	20.69	18.49	19.96	11.46	17.52	17.45	20.96	19.49
Na_2O	0.04	0.05	0.08	0.09	0.02	0.04	0.06	0.07	0.05	0.07	0.08	0.09	0.06	0.07	0.05	0.06	0.09	0.08	0.07	0.09
K_2O	0.16	0.14	0.17	0.18	0.2	0.21	0.17	0.13	0.12	0.15	0.18	0.16	0.09	0.1	0.09	0.12	0.13	0.13	0.12	0.14
P_2O_5	0.02	0.03	0.15	0.01	0	0.02	0	0.14	0.02	0	0.13	0	0	0	0.02	0	0.03	0.01	0.05	0.07
LOI	7.52	5.62	6.92	6.52	7.92	6.96	8.17	6	9.9	8.8	10.98	9.54	10.96	8.98	9.91	11.93	7.59	9.96	6.1	8.25
Cu	0.03	0.035	0.033	0.028	0.032	0.027	0.036	0.034	0.031	0.41	0.036	0.039	0.04	0.03	0.038	0.041	0.034	0.032	0.037	0.042
Pb	0.01	0.012	0.013	0.01	0.011	0.01	0.015	0.014	0.01	0.015	0.016	0.013	0.01	0.015	0.014	0.011	0.012	0.01	0.014	0.016
Zn	0.035	0.037	0.035	0.032	0.036	0.031	0.04	0.038	0.034	0.042	0.043	0.041	0.041	0.036	0.041	0.03	0.036	0.031	0.033	0.039
Co	0.001	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002
Ni	0.002	0.002	0.002	0.001	0.002	0.001	0.002	0.001	0.001	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.001	0.001	0.001	0.002
Cr	0.003	0.002	0.002	0.002	0.002	0.001	0.002	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.002
Total	**99.07**	**100.1**	**99.14**	**99.3**	**99.31**	**99.79**	**99.86**	**99.86**	**99.52**	**99.89**	**99.72**	**99.97**	**99.54**	**99.61**	**100.6**	**97.2**	**99.38**	**99.56**	**101**	**99.83**

Table 3: Ratio of major oxides of host rock of base metals, Sawar-Bajta area

Sample	SiO2/Al2O3	Fe2O3/MgO	MgO/K2O+Na2O
1	2	0.03	98.75
2	2.56	0.04	109.7
3	3.5	0.04	61.92
4	2.4	0.05	68.85
5	2.69	0.09	84.91
6	2.57	0.13	75.84
7	2.43	0.08	91.04
8	2.51	0.08	115.6
9	3.16	0.1	116.23
10	2.45	0.13	83.86
11	1.87	0.11	59.73
12	1.7	0.09	76.96
13	2	0.04	137.93
14	2.43	0.05	108.76
15	2.77	0.05	142.57
16	2.64	0.1	63.67
17	2.92	0.09	79.64
18	3.38	0.09	84
19	2.58	0.05	110.32
20	3.63	0.04	84.74

Calcium Oxide (CaO):

Calcium oxide shows moderate variation trend with unimodel characterstics.

Magnesia (MgO):

The variation range of magnesia is wide in comparision with calcium oxide.

Ferric Oxide (Fe2O3):

Ferric Oxide shows moderate variation with unimodal character.

Manganese Oxide (MnO):

The variation range of manganese oxide is wide and characterstically unimodal.

Phosphorous Pentaoxide (P2O5):

Generally, P2O5 is poorly represented in most of the samples.

Loss On Ignition (LOI):

Loss on ignition is usually high and varies within a moderate range.

Geochemistry of the whole rocks

An attempt has been made to determine the geochemical analysis of the major oxides in the mineralised zones (table-4 and 5) and the variation diagrams and frequency distribution of major oxides in host rocks have also been shown (Fig.5, 6 and7). The curves are showing the variation diagrams of the major oxides in the whole rocks (Fig.8) and the frequency distribution of the major oxides (Fig.9 and 10).

Silica (SiO2)

Silica shows moderate variation with unimodal frequency trend.

Titania (TiO2)

Titania shows moderate variation with unimodal frequency trend.

Table 4: Analytical results of major oxides of whole rock in Sawar-Bajta area

(values in wt %)

Sample	B 1	B 3	B 4	B 5	B 7	B 8	B 16	B 17	B 18	G 2	G 4	S 5	S 6	S 7	T 2	T 3	T 4	T 6	T 7	T 9
SiO_2	17.22	17.28	18.49	19.48	18.51	15.04	16.11	19.16	16.88	15.62	17.66	14.83	16.78	17.71	14.85	15.21	18.26	18.25	15	16.03
TiO_2	0.22	0.09	0.27	0.27	0.35	0.33	0.24	0.29	0.11	0.09	0.22	0.24	0.26	0.22	0.21	0.26	0.11	0	0.2	0.18
Al_2O_3	6.5	7.12	7.81	7.55	5.6	7.45	5.37	7.43	7.73	6.59	7.15	5.77	7.09	6.11	6.88	7.23	7.22	7.42	7.07	6.15
Fe_2O_3	2.99	4.31	6.69	5.8	4.86	8.2	9.07	6.12	5.64	3.51	2.11	7.11	3.72	3.42	12.97	4.9	2.54	3.58	13	3.68
MnO	0.03	0.08	0.06	0.09	0.27	0.45	0.5	0.05	0.06	0.14	0.09	0.13	0.27	0.09	0.66	0.04	0.03	0.05	0.41	0.06
CaO	38.43	44.9	40.49	39.49	35.06	38.96	37.68	35.14	40.27	42.88	38.53	36.17	41.76	39.64	34.6	38.03	36.55	36.15	33.42	38.5
MgO	17.41	17.06	17.47	17.24	18.52	18.41	20.94	18.77	16.59	17.53	17.24	17.69	17.24	18	17	17.24	15.82	18.82	19.71	18.59
Na_2O	0.8	0.3	0.6	0.4	0.8	0.2	0.8	0.7	0.9	0.8	0.5	0.2	0.8	0.6	0.2	0.4	0.4	0.2	0.4	0.3
K_2O	1	0.4	1	0.9	2.2	0.4	0.8	0.7	0.4	0.4	0.2	0.3	0.6	1.6	0.3	0.3	0.9	0.4	0.6	0.7
P_2O_5	0	0	0.18	0.17	0.05	0	0.01	0	0.13	0	0.39	0.01	0	0	0	0	0.01	0	0.01	0
LOI	6.6	6	5	5.6	5.98	7.89	5.99	7.8	8.19	7.45	8.32	9.98	5.97	7.13	6.29	7.6	8.13	8.92	4.32	8.9

Table 5: Ratio of major oxides of whole rock, Sawar-Bajta area

Sample	SiO_2/Al_2O_3	Fe_2O_3/MgO	MgO/Na_2O+K_2O
B 1	2.65	0.17	9.6
B 3	2.43	0.25	24.37
B 4	2.37	0.38	10.92
B 5	2.58	0.34	13.26
B 7	3.31	0.26	6.17
B 8	2.02	0.45	30.68
B 16	3	0.43	13.09
B 17	2.58	0.33	13.41
B 18	2.18	0.34	12.76
G 2	2.37	0.2	14.61
G 4	2.47	0.12	24.63
S 5	2.57	0.4	35.38
S 6	2.37	0.22	12.31
S 7	2.9	0.19	8.18
T 2	2.16	0.76	34
T 3	2.1	0.28	24.63
T 4	2.53	0.16	12.16
T 6	2.46	0.19	31.37
T 7	2.12	0.66	19.71
T 9	2.61	0.2	18.59

Variation diagrams of the major oxides in host rocks of base metals, Sawar-Bajta area

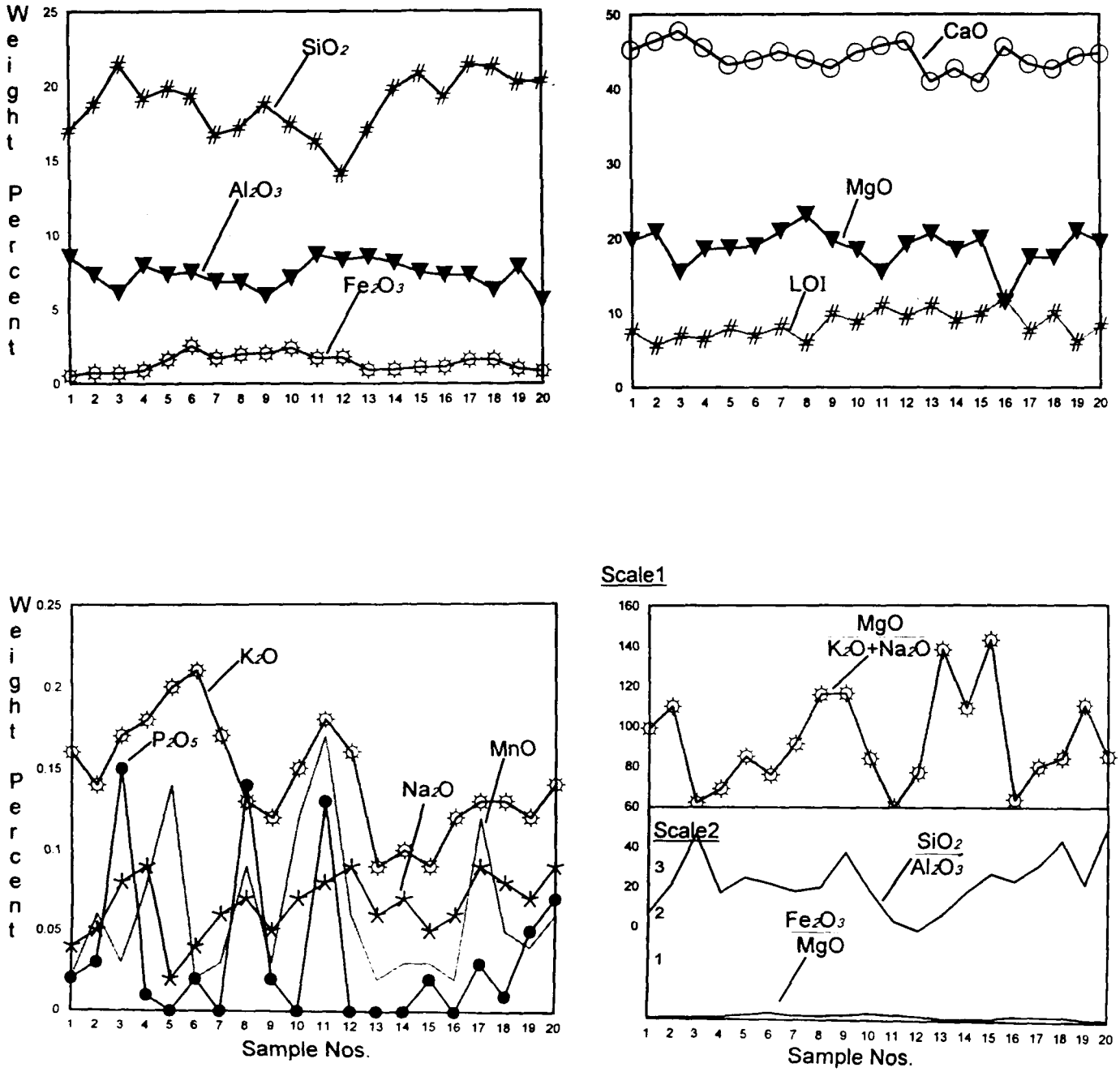


FIG.NO.5

Frequency distribution of major oxides in host rocks of base metals, Sawar-Bajta area

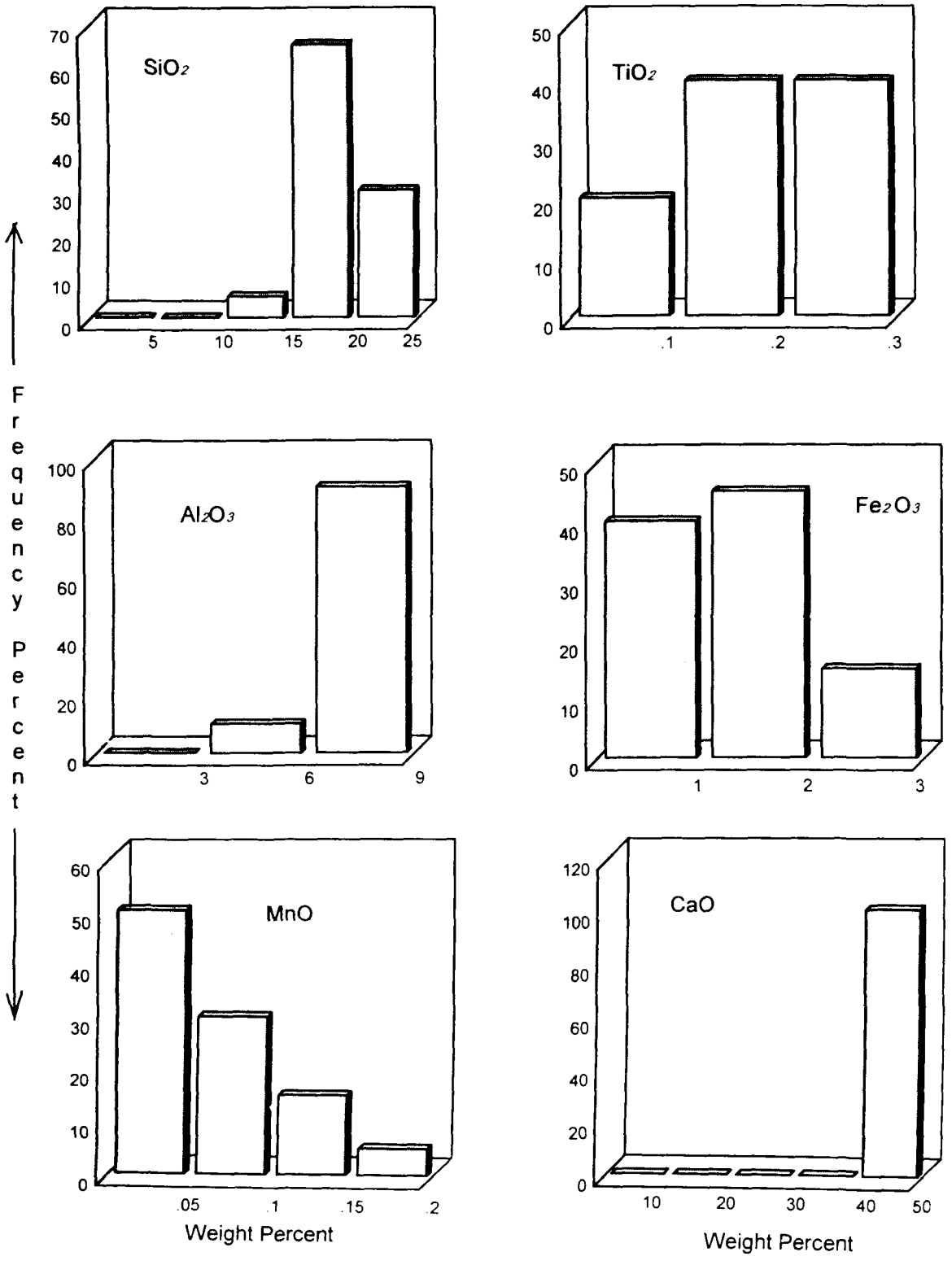


FIG. NO. 6

Frequency distribution of major oxides in host rocks of base metals, Sawar-Bajta area

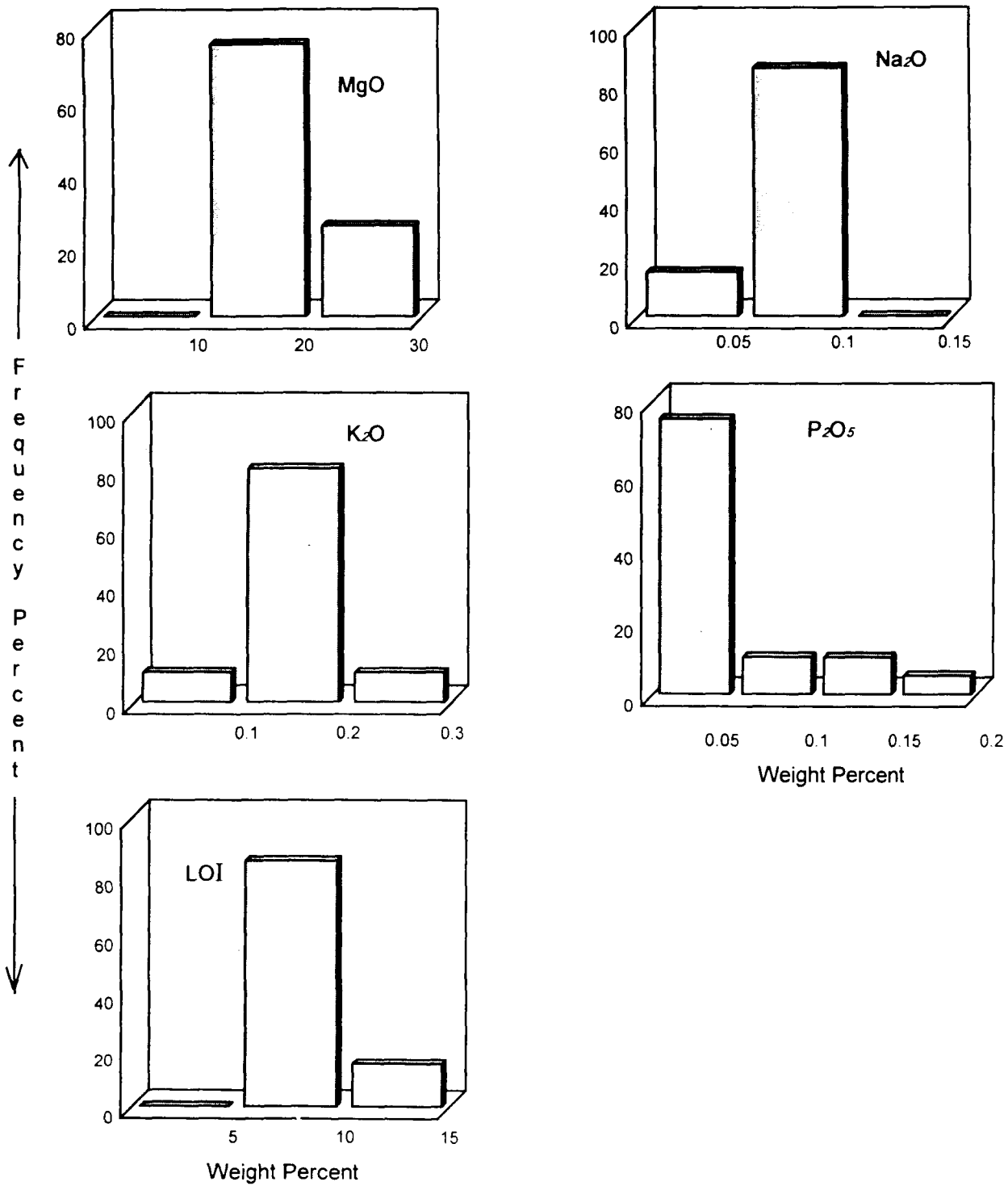
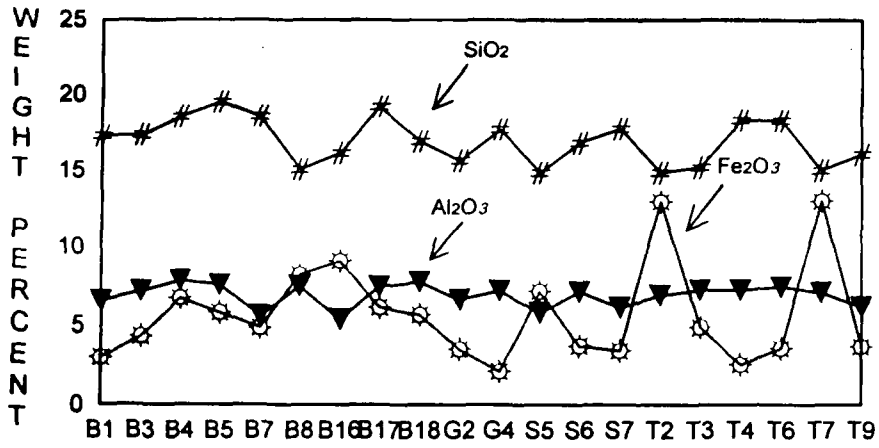
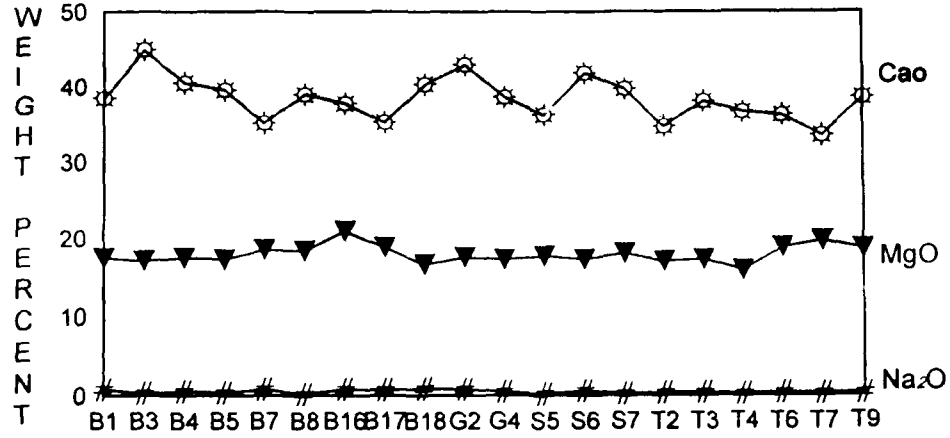
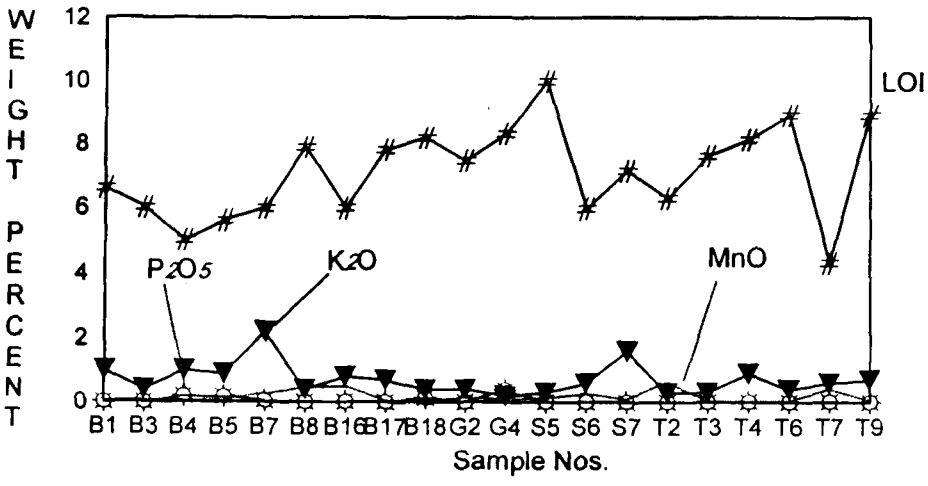


FIG. NO. 7

Variation diagrams of the major oxides in whole rocks, Sawar-Bajta area







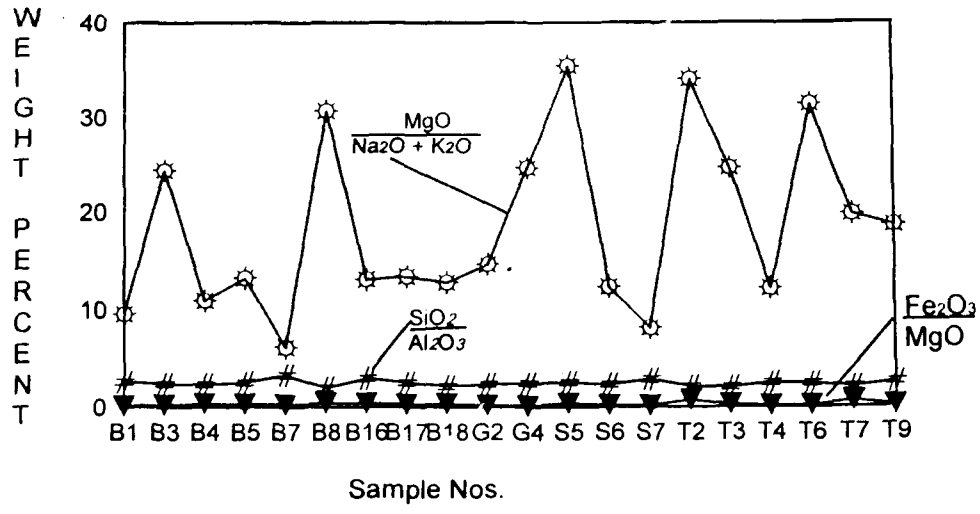


FIG. NO.8

Frequency distribution of major oxides in whole rocks, Sawar-Bajta area

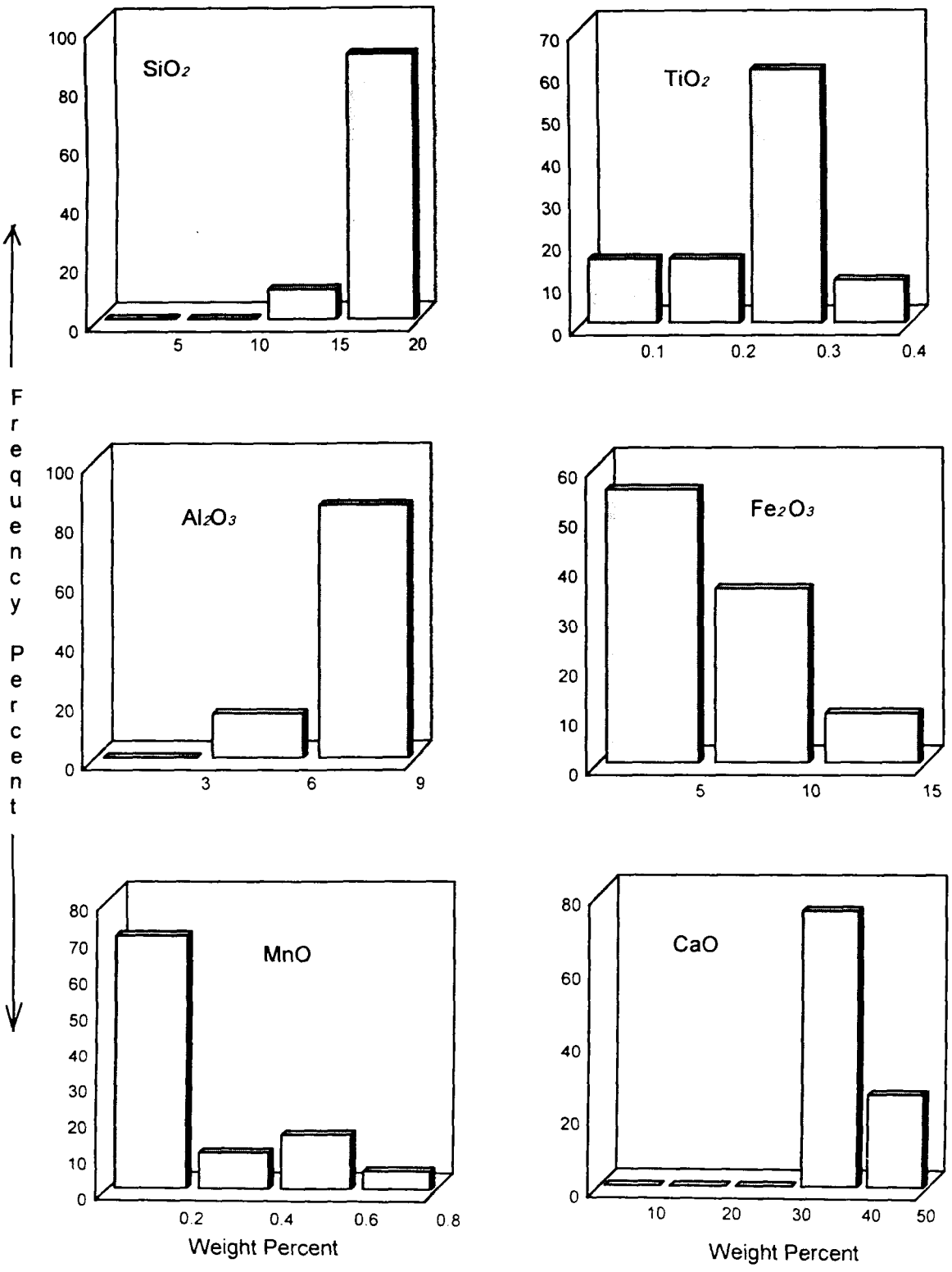


FIG. NO. 9

Frequency distribution of major oxides in whole rocks, Sawar-Bajta area

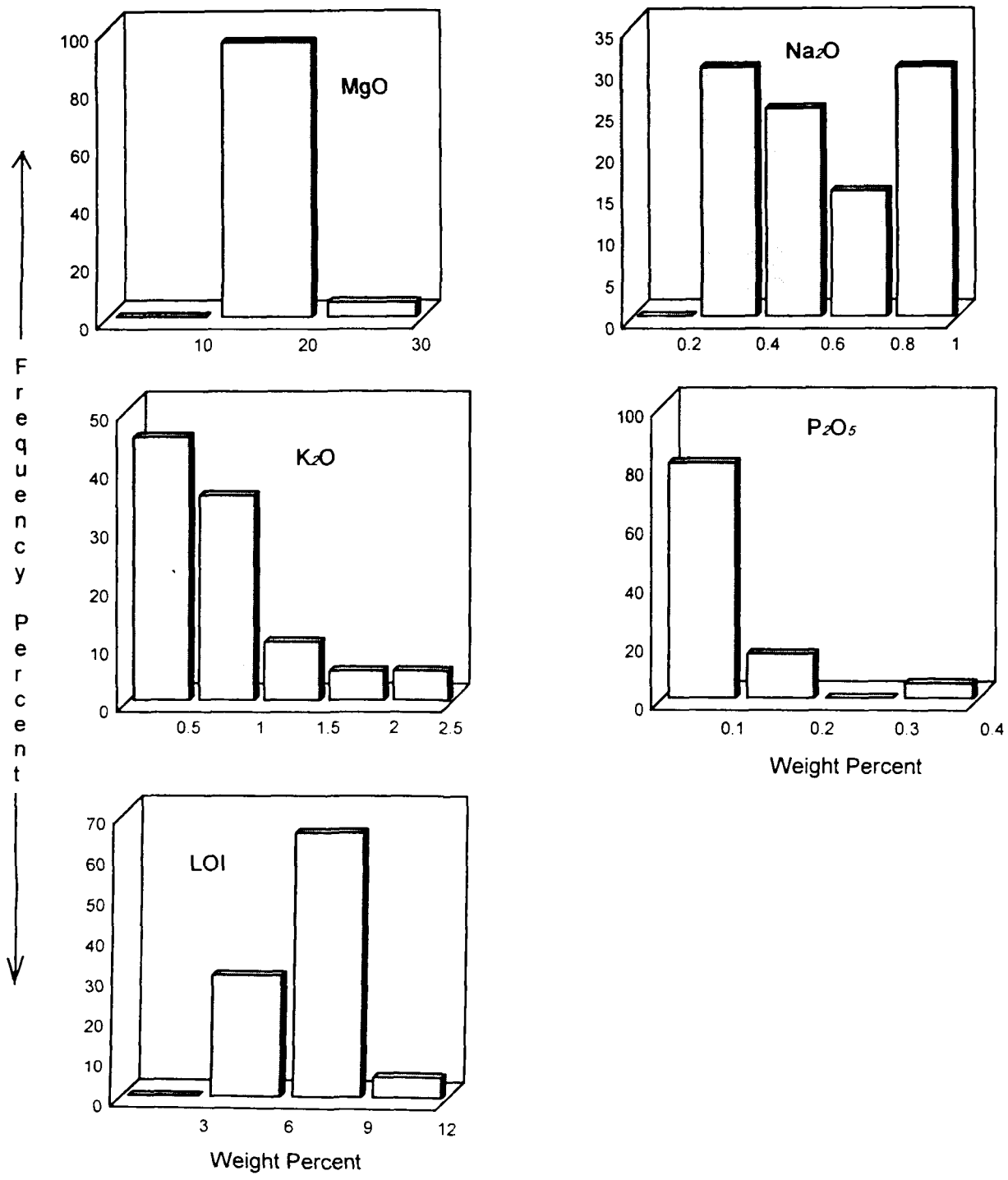


FIG. NO.10

Alumina (Al2O3)

Alumina shows unimodal frequency trend and it is moderately concentrated.

Alkalies (Na2O and K2O)

Soda is poorly represented with moderate variation and unimodal frequency trend.

Potash also shows moderate variation but of wider range in comparision with soda.

Calcium Oxide (CaO)

Calcium oxide shows moderate variation with unimodal frequency trend.

Magnesia (MgO)

Magnesia shows moderate variation with unimodal frequency trend.

Ferric oxide (Fe2O3):

Ferric oxide is fairly variable. It shows unimodal frequency trend.

Manganese oxide (MnO)

The range of manganese oxide is fairly variable and characteristically shows unimodal frequency trend.

Phosphorous Pentaoxide (P2O5)

Phosphorous Pentaoxide is poorly represented with low variation trend and unimodal frequency distribution.

Loss On Ignition (LIO)

Loss on Ignition is fairly variable and shows unimodal frequency trend.

Discussion

An attempt has been made to compare the mutual geochemical relation of major oxides of the host rocks with those of whole rocks.

Silica (SiO2):

From the above observation it is imperative that SiO2 decreases towards the lode. The SiO2/Al2O3 ratio of the individual rock samples increases towards the lode. Na2O shows increasing values with decreasing concentration of SiO2 and this is also the tendency of K2O. Iron oxide also shows an increasing tendency with the decrease of SiO2.

Alumina (Al2O3):

The alumina content in lower marble indicates that its concentration decreases towards the lode but there is no appreciable change in the alumina content.

Titania (TiO2):

It is evident that titania remains mostly unchanged during the processes of alteration and metamorphism.

Ferric oxide (Fe2O3):

Ferric oxides have appreciably higher values in the rocks nearest to the lode.

Alkalies (Na2O+K2O):

The samples collected away from the lode have lower concentration of Na2O and K2O in comparision with the samples collected from the nearby lode.

Magnesia (MgO):

It is evident that magnesia does not show any appreciable change.

The Fe2O3/MgO ratio in different samples of the host rocks taken from different localities away from the lode and the rocks nearer to the lode do not show any appreciable change.

The average ratio of MgO/(K2O+Na2O) in the rocks away from the lode have much greater values in comparision with the rocks nearer to the lode. This shows that magnesia dominates over alkalies in both the zones.

Calcium oxide (CaO):

It is evident that the value of CaO in the samples collected from or nearer to the lode have higher values in comparision with the samples collected, away from the lode.

The rest of the constituents viz; P2O5, MnO which occur in minute quantities do not show any significant variation trend.

The variation trend of the major oxides in the host rocks sampled from different localities as discussed above are summarised below.

1. There is a depletion of SiO2 near the lode.
2. There is no appreciable change in the concentration of Al2O3. However, a marginal reduction of Al2O3 near the lode has been observed.
3. A slightly increasing tendency is indicated by K2O and Na2O towards the lode.
4. MnO indicates a slightly increasing trends towards the lode.
5. The concentration of Fe2O3 increases towards the lode.
6. The concentration of MgO decreases towards the lode. But the difference is very marginal.
7. CaO decreases in its concentration towards the lode.
8. P2O5 is slightly increasing towards the lode. But the change is insignificant.

Distribution trend and salient characteristic features of trace elements of the host rocks

General statement:

Goldschmidt, (1937) made certain useful observations for trace element distribution in rocks and minerals and proposed a geochemical classification based on their chemical affinity and also stated that the distribution of chemical elements in the different phases depends upon the electronic configuration of the atoms. Subsequently, Mason, (1958), Tauson, (1965), Burns, and Fyfe, (1966 and 67) added further valuable informations on the trace eliments.

In the present case, some of the trace elements such as Cu, Pb, Zn, Co and Cr in the host rocks were determined in an attempt to examine their relative geochemical abundance (table-2). The samples of the country rocks have been collected from the outcrops and bore holes.

Distribution Trend

The salient characteristic features of the trace elements are as under.

Lead (Pb):

There is a slight variation in the values of galena of the lower marble of Sawar-Bajta area. It varies from 100 to 160 ppm.

Zinc (Zn):

The concentration of zinc is higher in comparision with lead but the values of zinc are slightly varying. They vary from 310 to 430ppm.

Copper (Cu):

The concentration of copper in lower marble is almost equal to the concentration of zinc but, the variation is slightly higher than the variation of zinc. The variation ranges from 270 to 420ppm.

Cobalt (Co):

The lower marble of the Sawar-Bajta area is poor in cobalt and the values are slightly varying. Their concentration ranges from 10 to 17ppm.

Nickel (Ni):

The concentration of nickel is slightly higher than cobalt in the lower marble of the Sawar-Bajta area. The values of nickel are varying from 10 to 22ppm.

Chromium (Cr):

The concentration of chromium is almost equal to the nickel. The value of chromium in the lower marble ranges 10 to 22ppm.

Evaluation:

From the abundance of the trace elements and their trends of distribution, as found in the host rocks, no definite opinion can be made regarding the behaviour of the trace elements.

Geochemistry of whole rocks

General statement

In all twenty ore samples representing the eight bore holes (Fig.3) were selected and analysed for the determination of the concentration of some of the major and trace elements (table-6). According to their level of abundance Pb, Zn, Cu have been categorised as major and Co,Ni,Cd,Cr,Bi

Table 6: Metallic contents in whole rock, Sawar - Bajta area (Values in wt.%)

Sample	B1	B3	B4	B5	B7	B8	B16	B17	B18	G2	G4	S5	S6	S7	T2	T3	T4	T6	T7	T9
Cu	0.125	0.093	0.067	1.21	1.51	1.56	0.59	0.72	0.79	0.23	0.34	0.4	1.12	0.6	0.9	0.91	0.2	0.21	0.18	0.6
Pb	4.32	4.1	1.13	0.53	0.64	0.67	0.14	1.12	0.13	3.11	3.45	3.61	2.15	3.49	3.27	2.98	5.24	5.59	4.1	4.2
Zn	3.21	2.91	0.9	0.41	0.51	0.42	0.96	0.99	0.98	2.3	3.3	2.92	1.57	1.78	1.98	4.26	3.59	2.09	1.2	2.2
Co	0.045	0.076	0.081	0.032	0.037	0.029	0.039	0.041	0.045	0.033	0.038	0.041	0.032	0.029	0.019	0.03	0.023	0.025	0.028	0.032
Ni	0.009	0.023	0.012	0.005	0.009	0.008	0.007	0.009	0.008	0.01	0.011	0.008	0.009	0.007	0.009	0.004	0.007	0.004	0.005	0.004
Cd	0.095	0.085	0.009	0.012	0.053	0.042	0.052	0.061	0.071	0.091	0.089	0.054	0.032	0.019	0.061	0.078	0.064	0.052	0.049	0.062
As	0.002	0.004	0.002	0.001	0.003	0.001	0.001	0.002	0.003	0.006	0.005	0.002	0.001	0.003	0.004	0.005	0.004	0.006	0.003	0.002
Cr	0.003	0.004	0.003	0.002	0.005	0.002	0.001	0.002	0.001	0.002	0.003	0.003	0.002	0.004	0.001	0.002	0.001	0.003	0.001	0.001
Bi	0.05	0.021	0.032	0.015	0.031	0.021	0.019	0.024	0.021	0.029	0.031	0.041	0.045	0.051	0.049	0.056	0.042	0.057	0.039	0.052
Co/Ni	5	3	7	6	4	4	6	5	6	3	3	5	4	4	2	8	3	6	6	8
Pb/Zn	1.3	1.4	1.3	1.3	1.3	1.6	0.1	1.1	0.1	1.4	1	1.2	1.4	2	1.7	0.6	7.9	6.5	5.7	6.5

and As as trace elements. The samples have been analysed on Atomic Absorption Spectrophotometer (model : 902) on which the minimum concentration of an element can be detected with 95% certainty. The elemental abundances have also been presented by the lateral variation curves (Fig.11 and 12). The mutual correlation coefficients of seven elements are calculated (table-7).

Distribution trends of Cu,Zn,Pb,Ni,Co,Cr,As and Bi

Cu, Pb and Zn are more abundant in the Sawar-Bajta area. Cobalt invariably dominate over nickel and has strong sympathetic relationship (table-7).

Attempts have also been made to establish the correlations of, Cu with Pb,Co,Zn and Ni (Fig.13); Zn with Cd, Ni,Co with Ni (Fig.14), Pb with Bi, As,Cd; Cd with Bi, AS,Cd; Cd with As;As with Bi,Zn; Bi with Zn; Cr with Co; Cr with Ni and Cd with Ni (Fig.15).

There is strong positive correlation with Pb and Zn. This correlation indicates the coexistance of Pb and Zn since their mineralisation. There is also a strong negative relation with copper and zinc and copper with lead.

Curves showing the variation trend of the metals in the sulphide ores

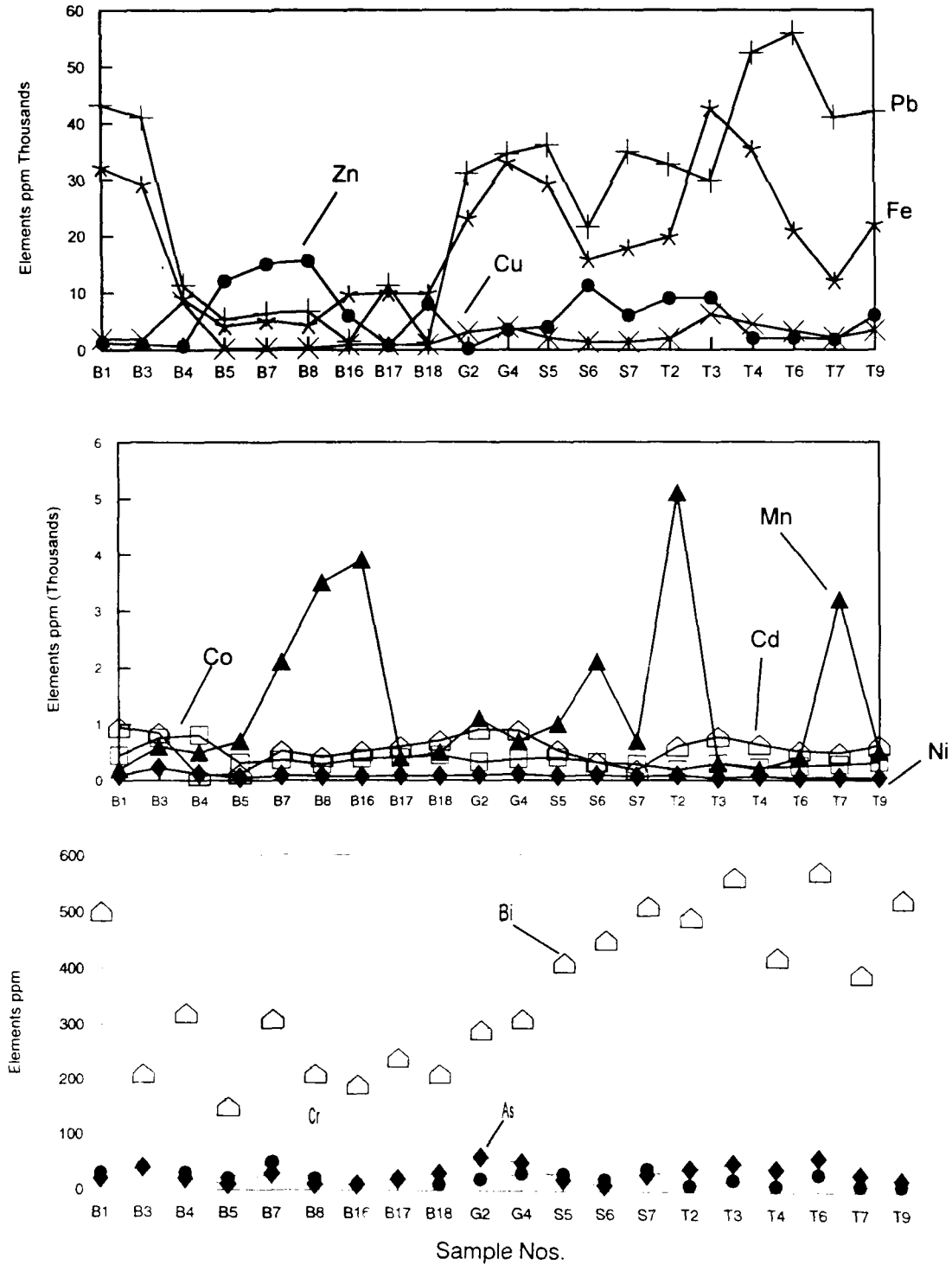


FIG. NO.11

Curves showing the variation trend of metallic ratio of the sulphide ores

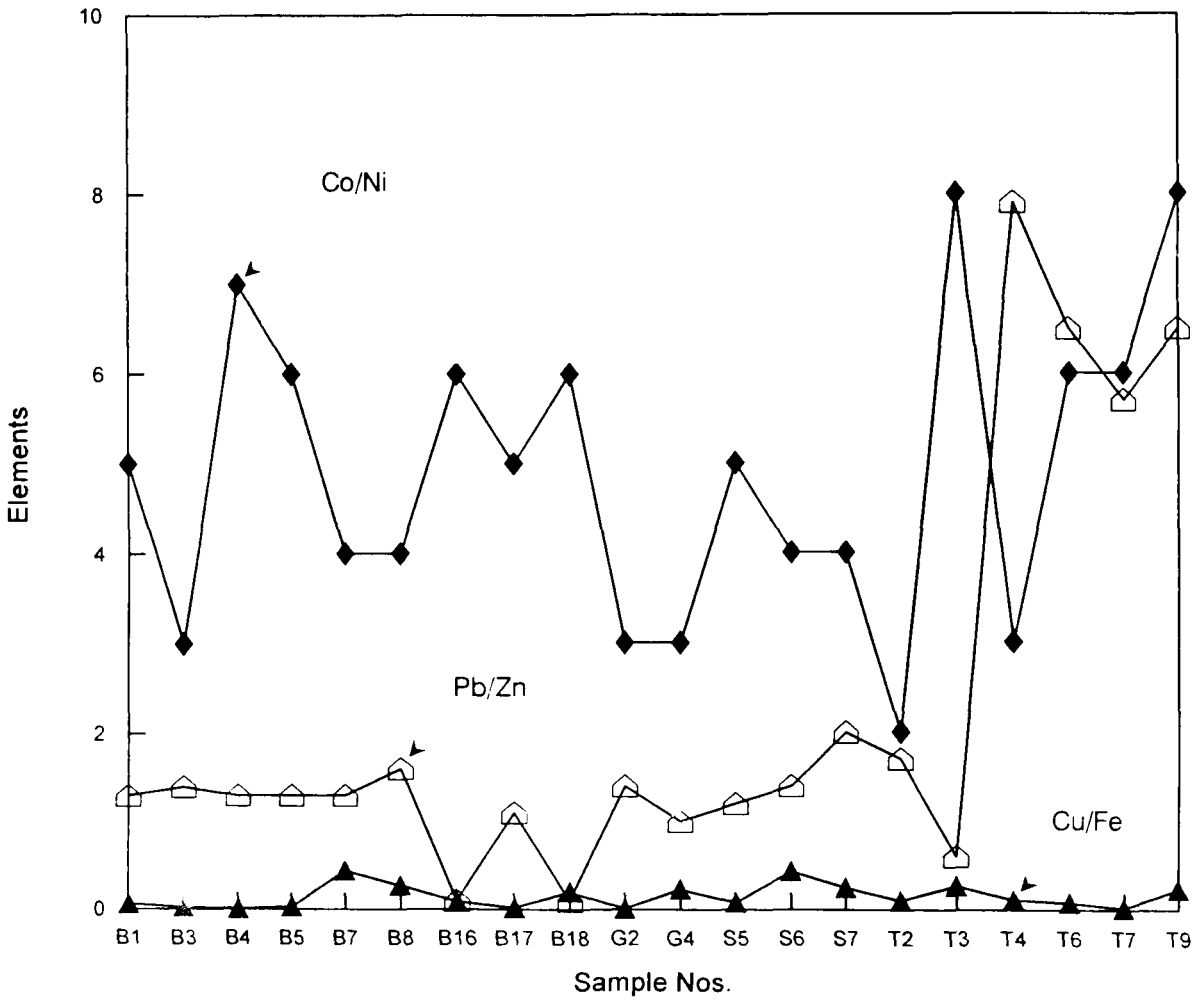
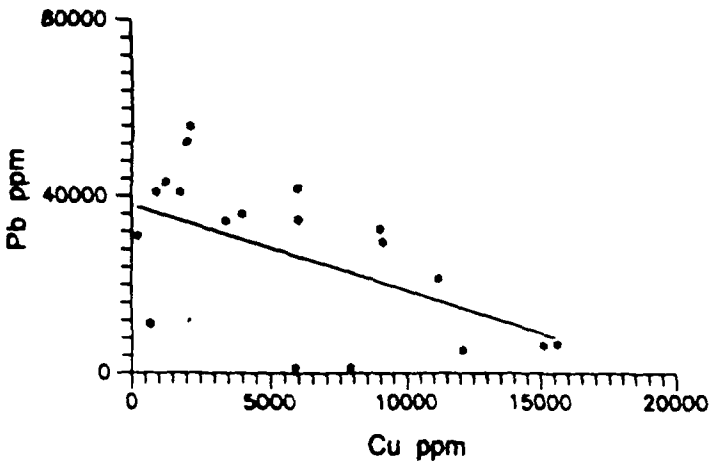


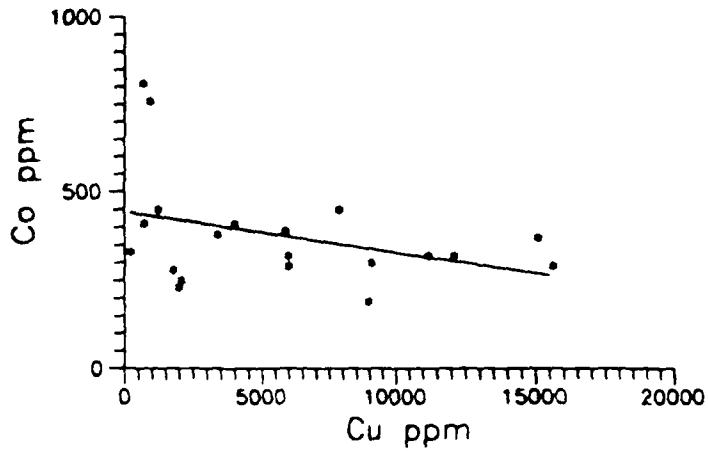
FIG. NO.12

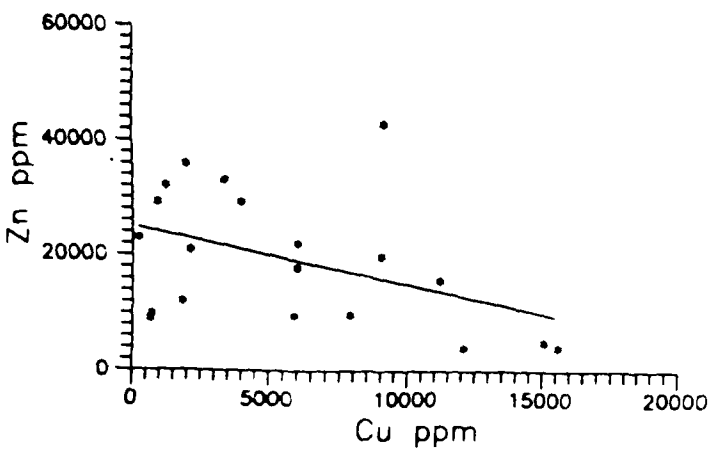
Table 7: Correlation of metallic contents of whole rock, Sawar-Bajta area

	Cu	Pb	Zn	Co	Ni	Cd	As	Cr	Bi
Cu	1								
Pb	-0.55	1							
Zn	-0.43	0.73	1						
Co	-0.36	-0.21	-0.06	1					
Ni	-0.27	-0.01	0.1	0.73	1				
Cd	-0.36	0.37	0.63	-0.02	0.27	1			
As	-0.37	0.56	0.56	-0.16	0.09	0.54	1		
Cr	0.02	0.05	0.03	0.4	0.44	-0.06	0.14	1	
Bi	-0.15	0.71	0.55	-0.39	-0.4	0.09	0.35	0.03	1

Variation Diagrams of Metallic Contents In Sulphide Ores







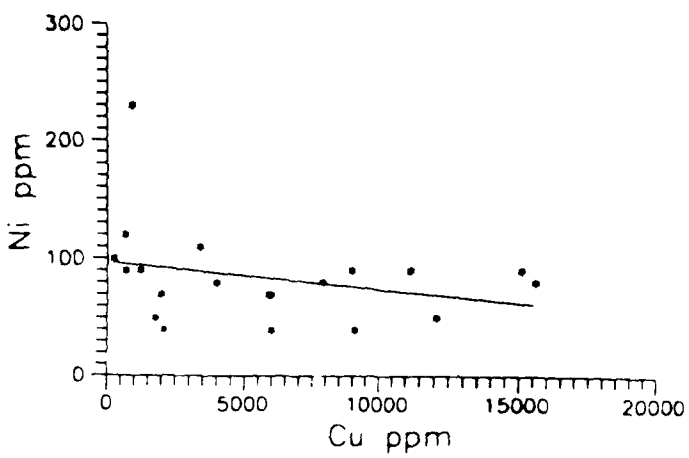


FIG. NO.13

Variation Diagrams of Metallic Contents in Sulphide Ores

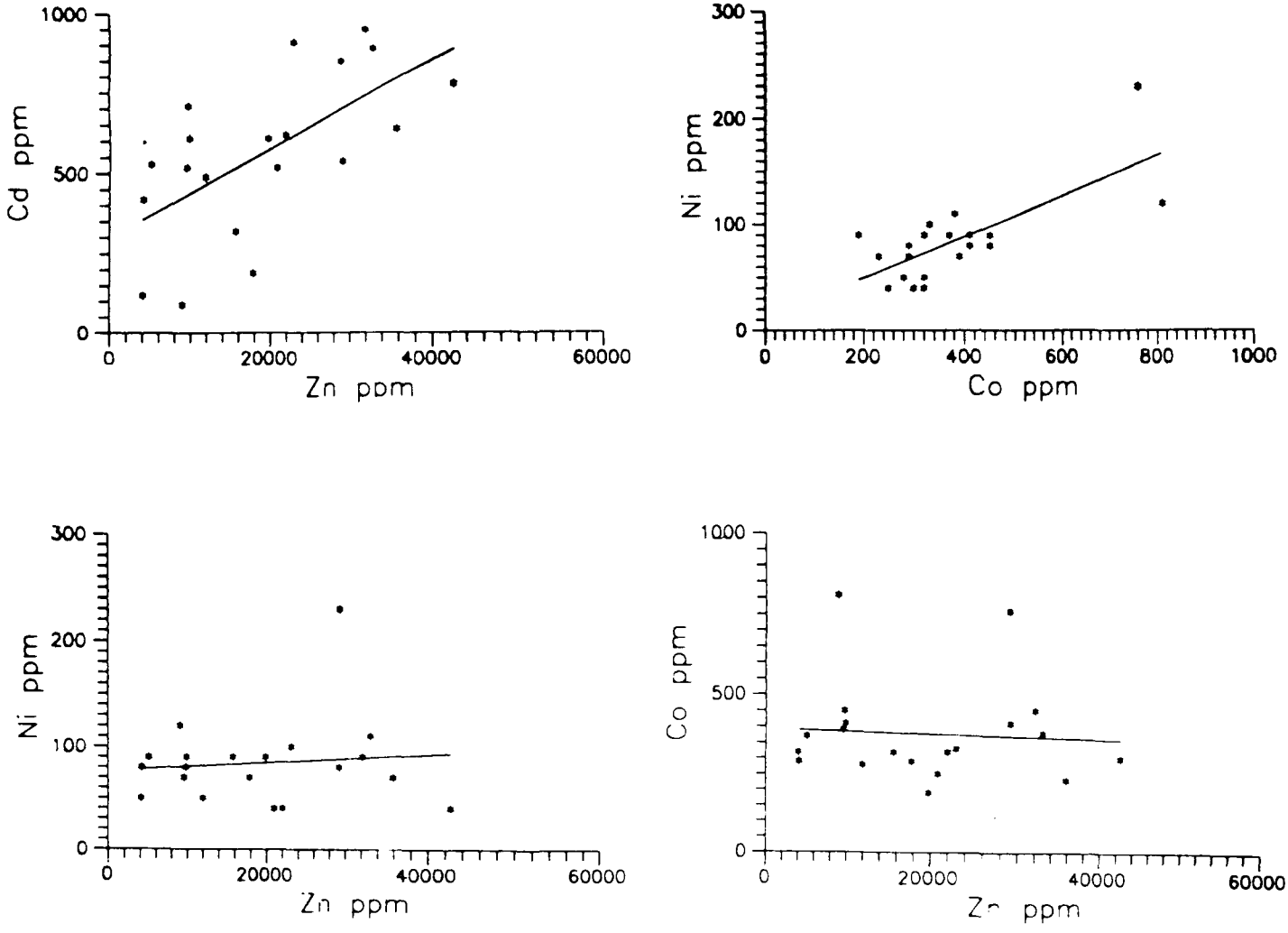


FIG. NO.14

Variation Diagrams of Metallic Contents in Sulphide Ores

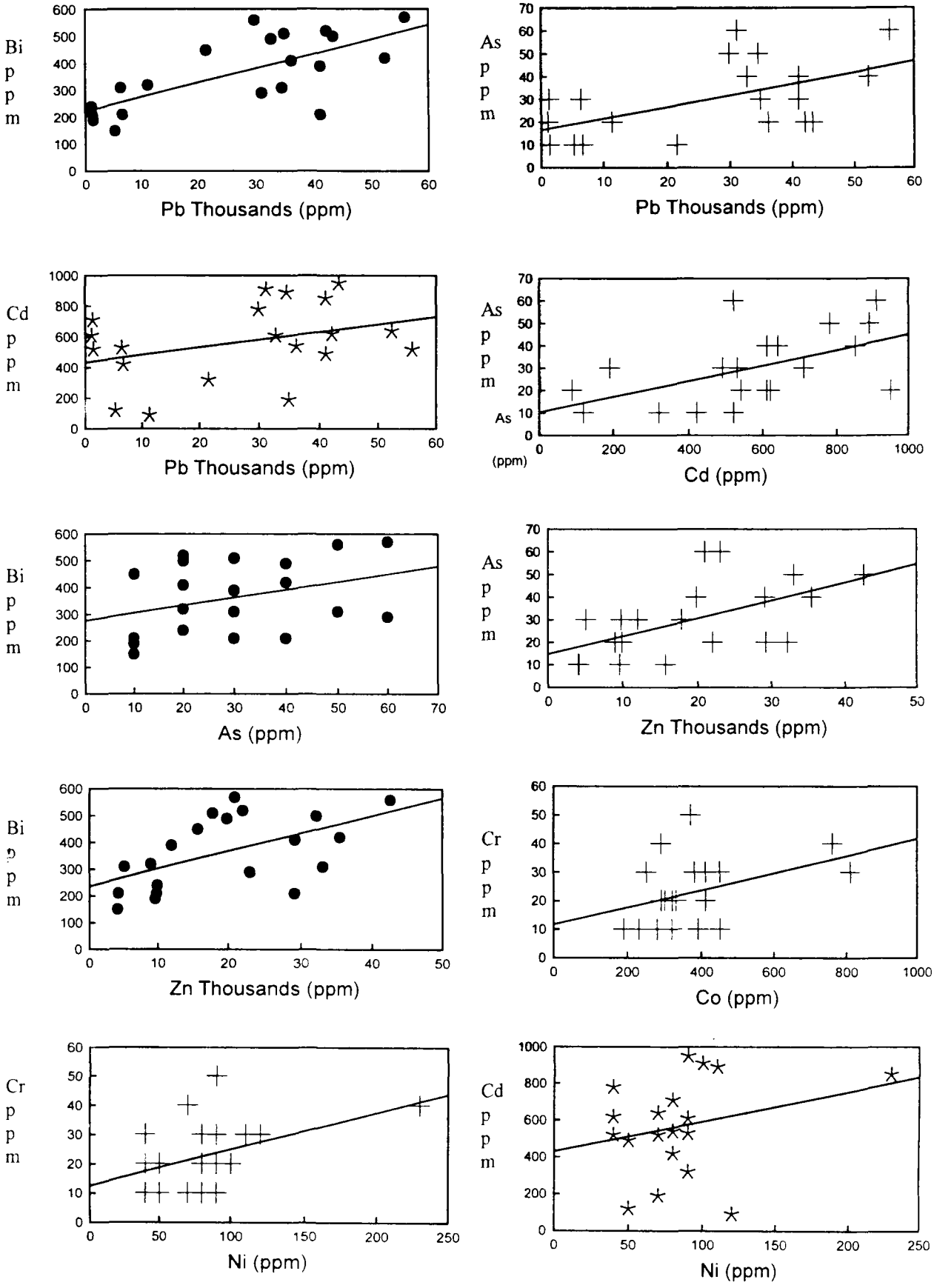


FIG. NO.15

Sulphide Ore Mineral Fractions

Five predominant minerals viz; chalcopyrite, pyrite, pyrrhotite, sphalerite and galena of the sulphide ores of the study area have been studied and their major and trace elements have been analysed on Electron Probe Microanalysis (Model:JXA-8600 Superprobe). The abundance and distribution trends of some trace elements in sulphide ore minerals often provide valuable informations regarding the genetic type of the ore deposit.

The trace element data of the ore minerals of Sawar-Bajta area have been shown in table 8 and 9 and illustrated in the form of histograms (Fig.16 to 25).

Distribution trend of elements

chalcopyrite :

The average concentration of cobalt in chalcopyrite is 317ppm. The variation of Co in the chalcopyrite with depth does not show any significant variation. There is practically no significant lateral variation of Co in chalcopyrite. The average concentration of Ni in the chalcopyrite is 26ppm. Like cobalt, there is no significant variation in Ni with depth.

Table 8: Major and trace elements in sulphide ores analysed on EPMA (wt%)

	PYRITE					SPHALERITE		
Sample	*B 1*	*B 2*	*G 2*	*T 4 (A)*	*T 4 (B)*	*G 2*	*G 4*	*G 6*
Cu	0.014	n.d.	0.008	0.012	n.d.	0.016	0.003	1.813
Fe	47.4	47.67	46.109	47.157	47.586	11.228	4.417	9.821
Zn	n.d.	n.d.	n.d.	n.d.	n.d.	54.026	61.76	54.448
S	50.663	43.388	53.527	53.905	53.793	35.107	32.941	35.299
Pb	1.21	0.094	0.183	0.185	0.039	n.d.	0.068	0.038
Cd	n.d.	0.003	n.d.	0.029	n.d.	0.474	0.509	0.411
Co	0.0838	0.093	0.058	0.31	0.058	0.015	0.033	0.06
Ni	0.037	0.029	0.14	n.d.	0.023	0.001	n.d.	n.d.
Mn	0.007	n.d.	n.d.	0.004	0.019	0.061	0.065	0.076
As	0.32	0.01	0.023	0.079	0.019	0.013	n.d.	n.d.
Sb	n.d.	0.009	n.d.	n.d.	0.001	0.031	0.019	n.d.
Bi	n.d.	0.054	n.d.	n.d.	0.02	n.d.	0.459	n.d.
Se	0.018	0.026	0.011	0.011	n.d.	0.005	0.083	0.032
Ag	n.d.	n.d.	n.d.	0.012	n.d.	n.d.	n.d.	n.d.
Au	0.02	0.027	n.d.	n.d.	0.122	0.121	0.137	0.29
Cr	0.02	0.017	n.d.	0.021	0.023	n.d.	0.026	0.002
Total	**100.547**	**96.214**	**100.057**	**101.724**	**101.702**	**101.098**	**100.249**	**102.289**

Table : 8 Contd....

	CHALCOPYRITE						
Sample	**B 16 (A)**	**B 16 (B)**	**B 17**	**G 6 (A)**	**G 6 (B)**	**G 6 (C)**	**S 5**
Cu	34.183	33.371	33.373	32.76	33.248	32.577	33.251
Fe	30.271	30.838	31.825	30.09	31.306	31.284	30.347
Zn	0.001	0.038	n.d.	n.d.	n.d.	n.d.	n.d.
S	34.389	35.119	35.245	36.059	36.179	36.186	33.909
Pb	n.d.	0.004	0.146	0.172	0.062	0.156	0.06
Cd	0.03	n.d.	0.019	0.008	n.d.	0.01	0.002
Co	0.03	0.024	0.022	0.041	0.022	0.039	0.044
Ni	n.d.	n.d.	n.d.	0.018	n.d.	n.d.	n.d.
Mn	n.d.	n.d.	0.002	n.d.	n.d.	0.006	n.d.
As	n.d.	n.d.	0.026	0.075	n.d.	0.064	n.d.
Sb	n.d.	n.d.	n.d.	0.026	n.d.	n.d.	n.d.
Bi	n.d.	0.232	n.d.	n.d.	0.188	0.178	0.18
Se	n.d.	0.023	0.009	0.011	n.d.	n.d.	n.d.
Ag	0.019	n.d.	0.03	0.067	0.021	0.087	0.023
Au	n.d.	n.d.	0.021	0.047	0.013	0.109	0.102
Cr	0.002	n.d.	0.023	n.d.	n.d.	0.003	0.019
Total	**98.926**	**99.649**	**100.742**	**99.376**	**101.128**	**100.698**	**97.938**

Contd...

Table : 8 Contd.....

	PYRRHOTITE					GALENA	
Sample	S 4 (A)	S 4 (B)	S 5	G 6 (A)	G 6 (B)	G 6 (A)	G 6 (B)
Cu	0.01	0.005	n.d.	n.d.	n.d.	0.001	n.d.
Fe	62.29	62.117	59.672	62.152	59.715	0.036	0.004
Zn	0.006	0.011	0.014	n.d.	n.d.	n.d.	n.d.
S	36.733	38.068	37.543	40.177	40.228	13.4	13.269
Pb	n.d.	n.d.	n.d.	n.d.	0.109	87.909	87.835
Cd	0.037	n.d.	n.d.	n.d.	0.076	n.d.	n.d.
Co	0.071	0.083	0.121	0.1	0.11	n.d.	n.d.
Ni	0.019	0.012	0.005	0.019	0.05	n.d.	n.d.
Mn	n.d.	n.d.	n.d.	0.005	n.d.	0.011	n.d.
As	0.025	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sb	n.d	0.006	0.019	n.d.	n.d.	n.d.	n.d.
Bi	0.09	n.d.	0.116	0.168	n.d.	0.302	0.336
Se	0.01	0.035	n.d.	n.d.	n.d.	n.d.	n.d.
Ag	n.d.	n.d.	0.027	n.d.	0.004	0.315	0.173
Au	n.d.	0.026	0.016	0.028	0.029	n.d.	n.d.
Cr	0.004	n.d.	0.017	0.003	n.d.	n.d	n.d.
Total	**99.294**	**100.363**	**97.552**	**102.833**	**100.323**	**101.975**	**101.617**

Abbreviation: n.d.=not detected on EPMA

Table 9 : Content of elements on ores of polished blocks analysed on EPMA, Sawar-Bajta area of Ajmer distt. (Values in ppm)

	PYRITE					SPHALERITE		
Sample	B 1	B 2	G 2	T 4 (A)	T 4 (B)	G 2	G 4	G 6
Cd	n.d.	30	n.d.	290	n.d.	4740	5090	4110
Co	8380	930	580	3100	580	150	330	600
Ni	370	230	1140	n.d.	230	10	n.d.	n.d.
Mn	70	n.d.	n.d.	40	190	610	650	760
As	3200	100	230	790	190	130	n.d.	n.d.
Sb	n.d.	90	n.d.	n.d.	10	310	190	n.d.
Bi	n.d.	540	n.d.	n.d.	200	n.d.	4590	n.d.
Se	180	260	110	110	n.d.	50	830	320
Ag	n.d.	n.d.	n.d.	120	n.d.	n.d.	n.d.	n.d.
Au	200	270	n.d.	n.d.	1220	1210	1370	2900
Cr	200	170	n.d.	210	230	n.d.	260	20

CHALCOPYRITE

Sample	B 16 (A)	B 16 (B)	B 17	G 6 (A)	G 6 (B)	G 6 (C)	S 5
Cd	300	n.d.	190	80	n.d.	100	20
Co	300	240	220	410	220	390	440
Ni	n.d.	n.d.	n.d.	180	n.d.	n.d.	n.d.
Mn	n.d.	n.d.	n.d.	n.d.	n.d.	60	n.d.
As	n.d.	n.d.	n.d.	750	n.d.	640	n.d.
Sb	n.d.	n.d.	n.d.	260	n.d.	n.d.	n.d.
Bi	n.d.	2320	1800	n.d	1880	1780	1800
Se	n.d.	230	n.d.	110	n.d.	n.d.	n.d.
Ag	190	n.d.	230	670	210	870	230
Au	n.d.	n.d.	1020	470	1030	1090	1020
Cr	20	n.d.	190	n.d.	n.d.	30	190

Table 9: Contd....

	PYRRHOTITE					GALENA	
Sample	S 4 (A)	S 4 (B)	S 5	G 6 (A)	G 6 (B)	G 6 (A)	G 6 (B)
Cd	370	n.d.	n.d.	n.d.	760	n.d.	n.d.
Co	710	830	1210	1000	1100	n.d.	n.d.
Ni	190	120	50	190	500	n.d.	n.d.
Mn	n.d.	n.d.	n.d.	50	n.d.	110	n.d.
As	250	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sb	n.d.	60	190	n.d.	n.d.	n.d.	n.d.
Bi	900	n.d.	1160	1680	n.d.	3020	3360
Se	100	350	n.d.	n.d.	n.d.	n.d.	n.d.
Ag	n.d.	n.d.	270	n.d.	40	3150	1730
Au	n.d.	260	160	2080	290	n.d.	n.d.
Cr	40	n.d.	170	80	n.d.	n.d.	n.d.

Histogram Showing Relative Abundance Of Certain Elements In Chalcopyrite; EPMA Data.(In Bajta Area)

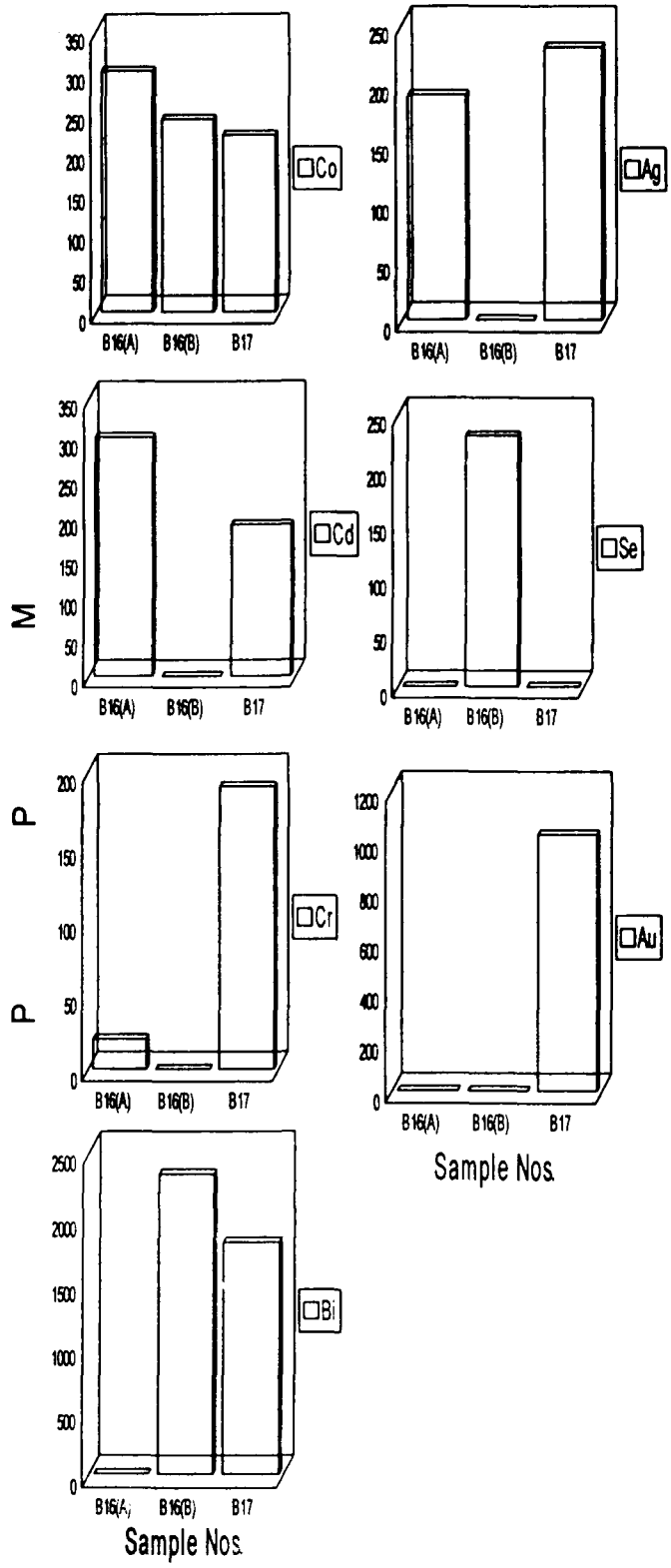


FIG. NO.16

Histogram Showing Relative Abundance Of Certain Elements In Chalcopyrite; EPMA Data.(In Sawar Area)

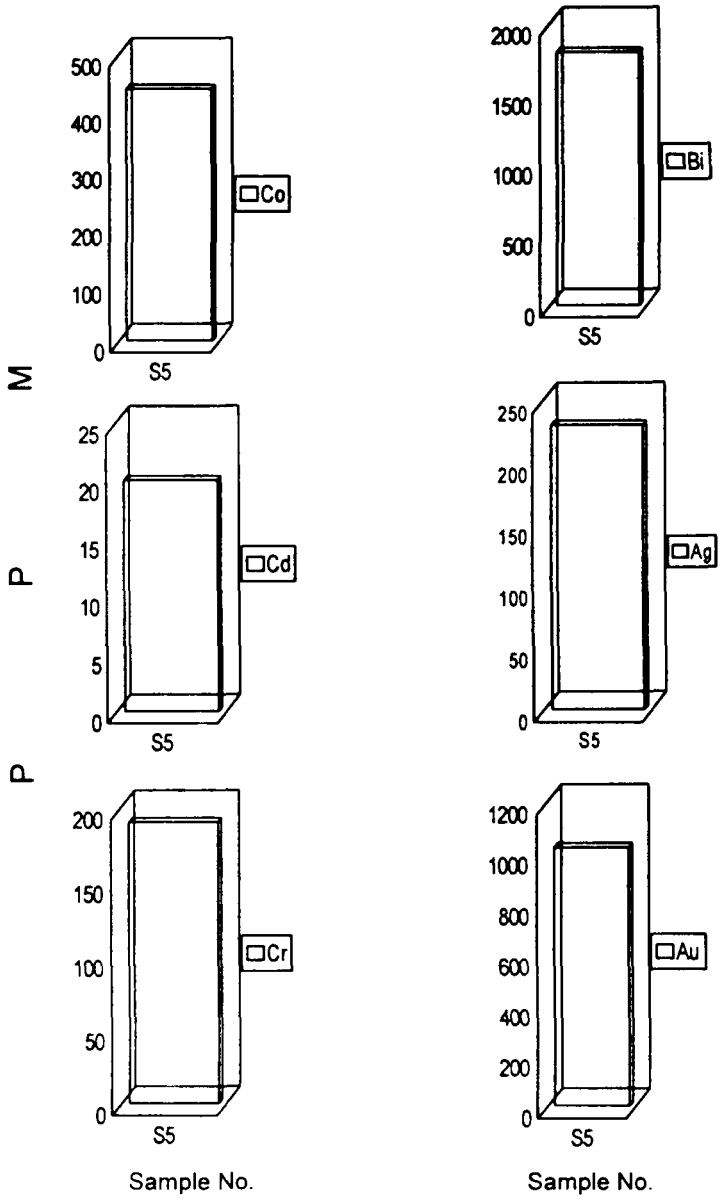


FIG. NO.17

Histogram Showing Relative Abundance Of Certain Elements In Chalcopyrite; EPMA Data.(In Ganeshpura Area)

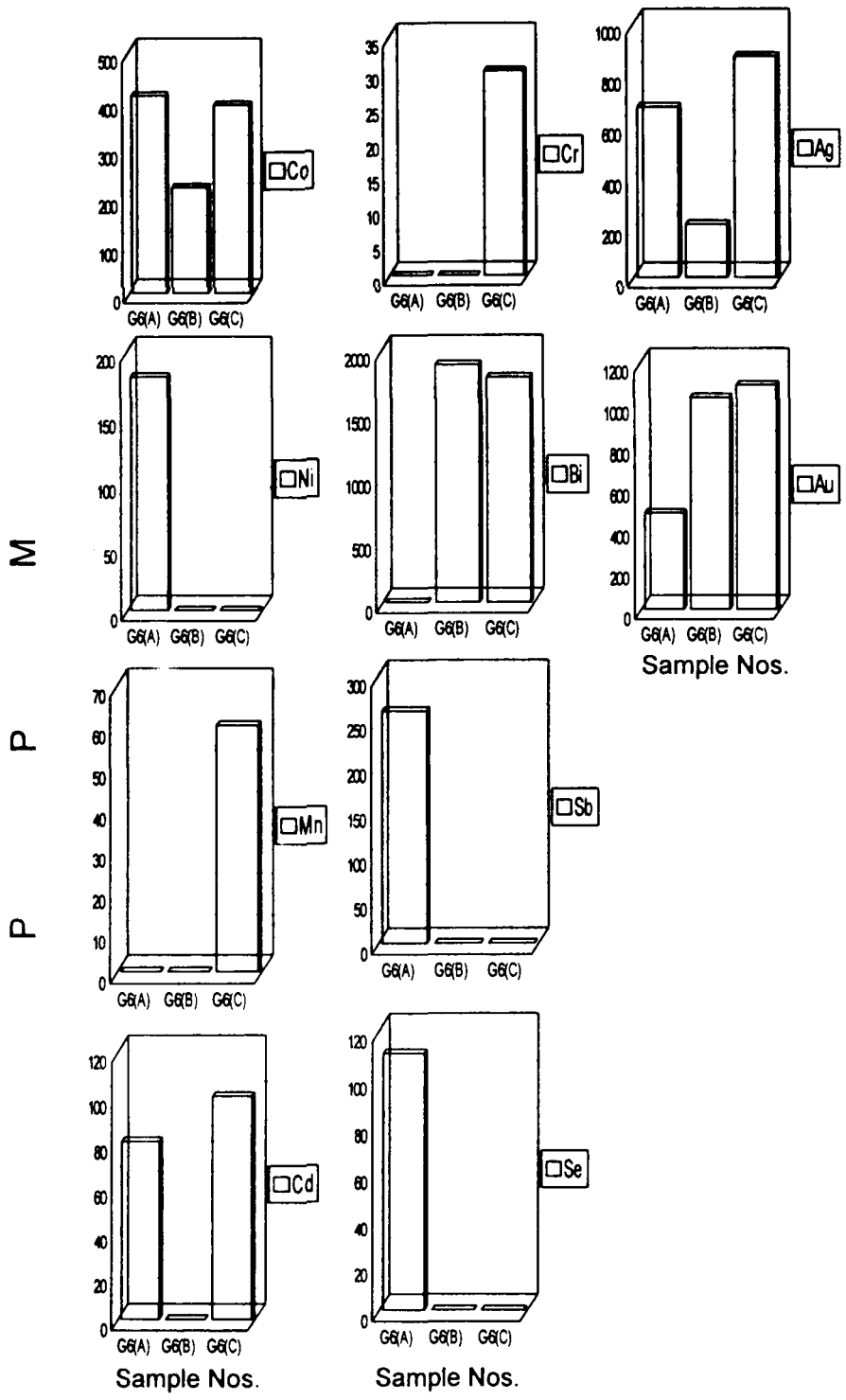


FIG. NO.18

Histogram Showing Relative Abundance of Certain Elements in Pyrrhotite; EPMA Data. (In Ganeshpura Area)

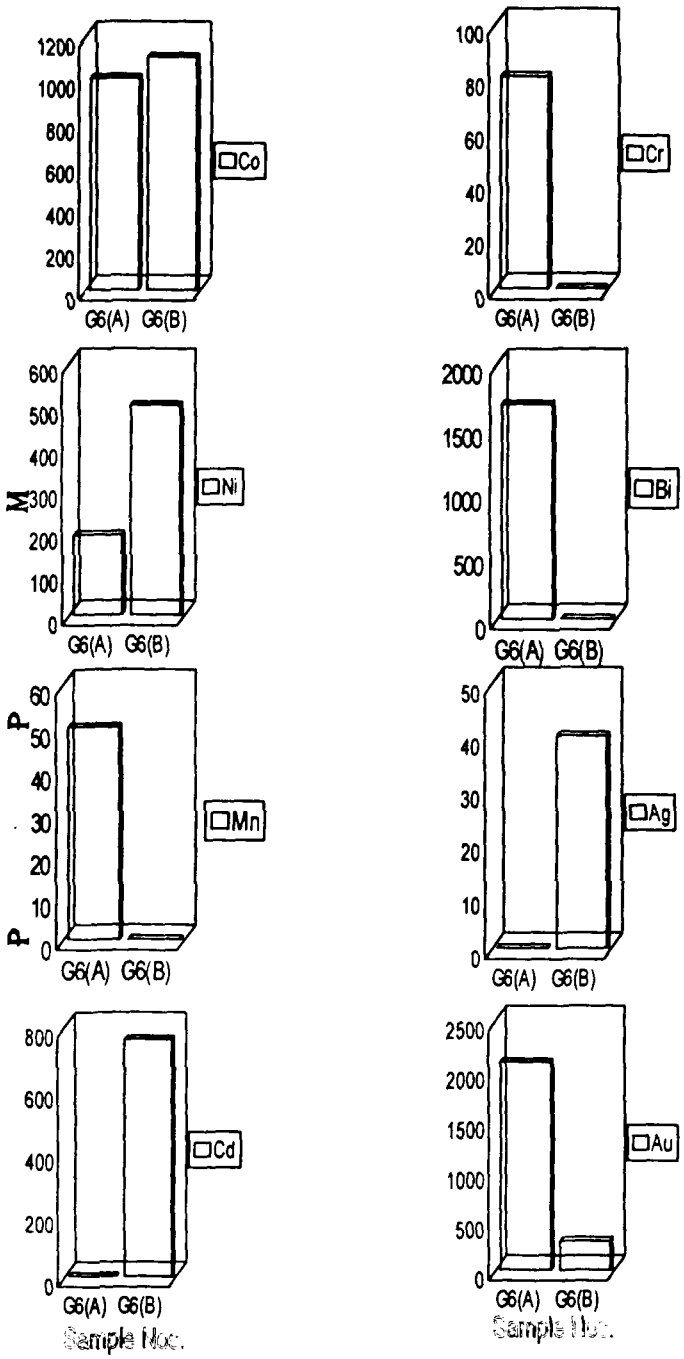


FIG. NO.19

Histogram Showing Relative Abundance of Certain Elements in Pyrrhotite; EPMA Data.
(In Sawar Area)

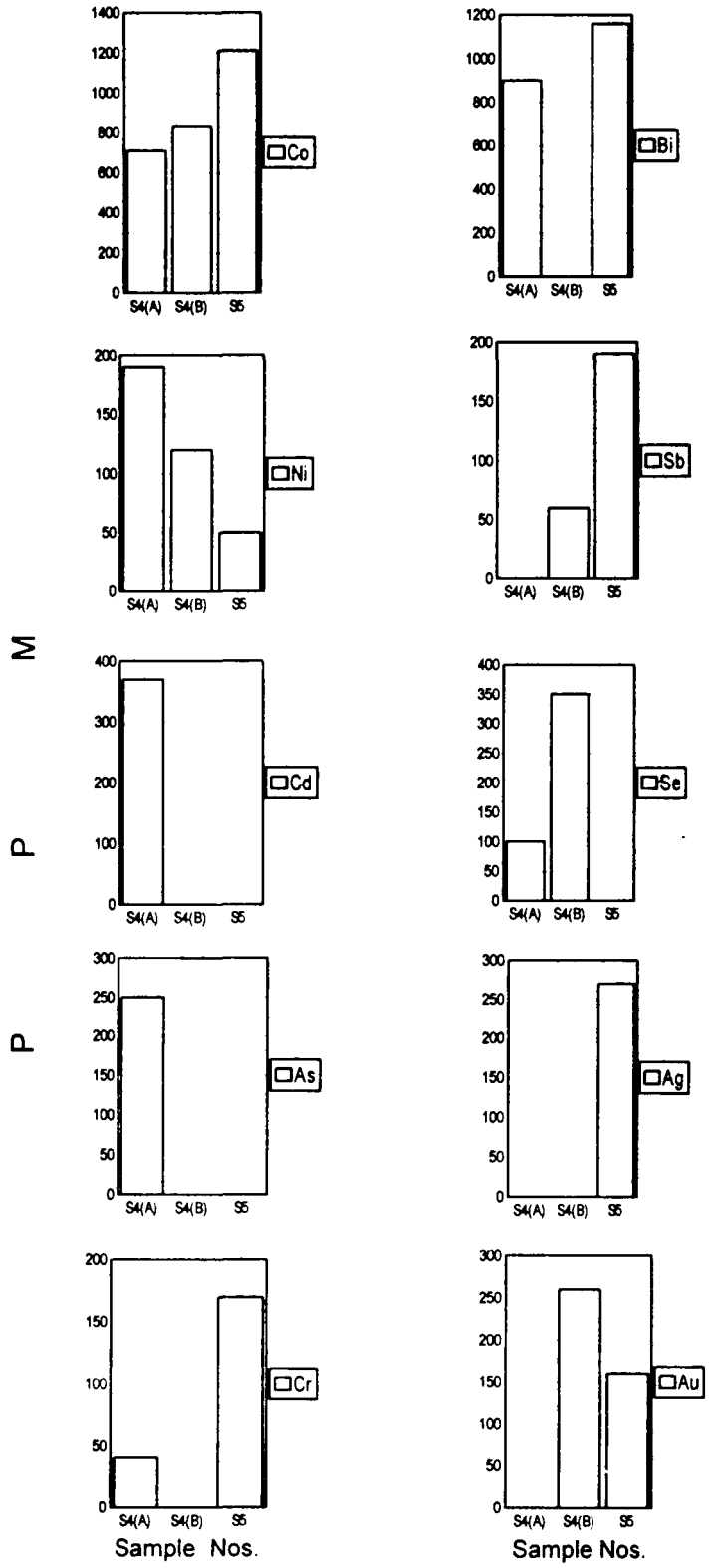


FIG. NO.20

Histogram Showing Relative Abundance of Certain Elements in Pyrite; EPMA Data. (In Bajta Area)

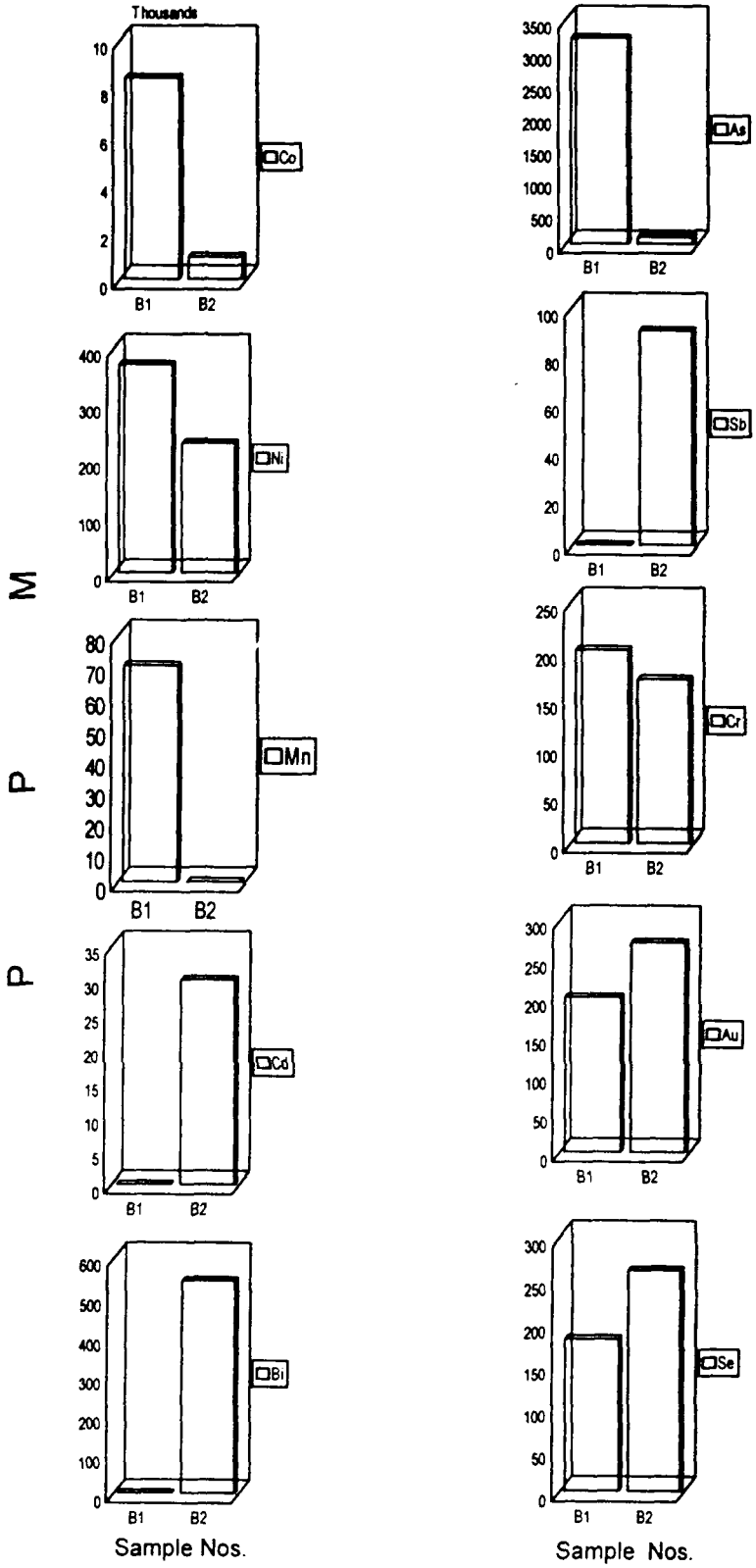


Fig.No.21

Histogram Showing Relative Abundance of Certain Elements in Pyrite EPMA Data. (In Ganeshpura Area)

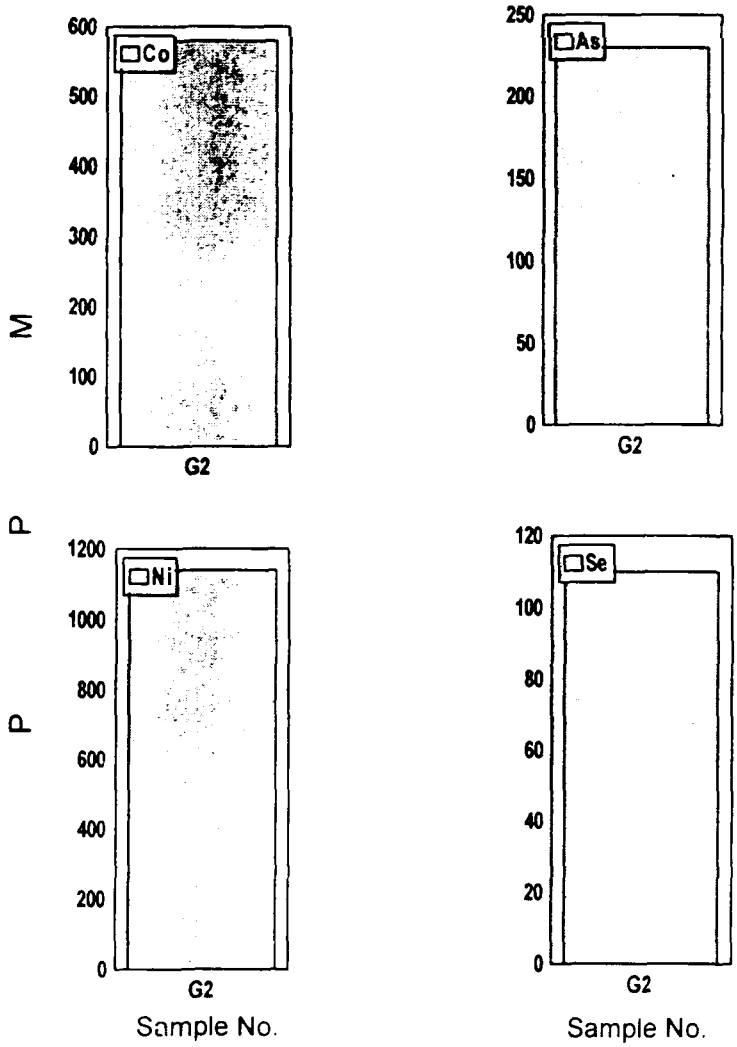


Fig.No.22

Histogram Showing Relative Abundance of Certain Elements in Pyrite EPMA Data. (In Tikhi Area)

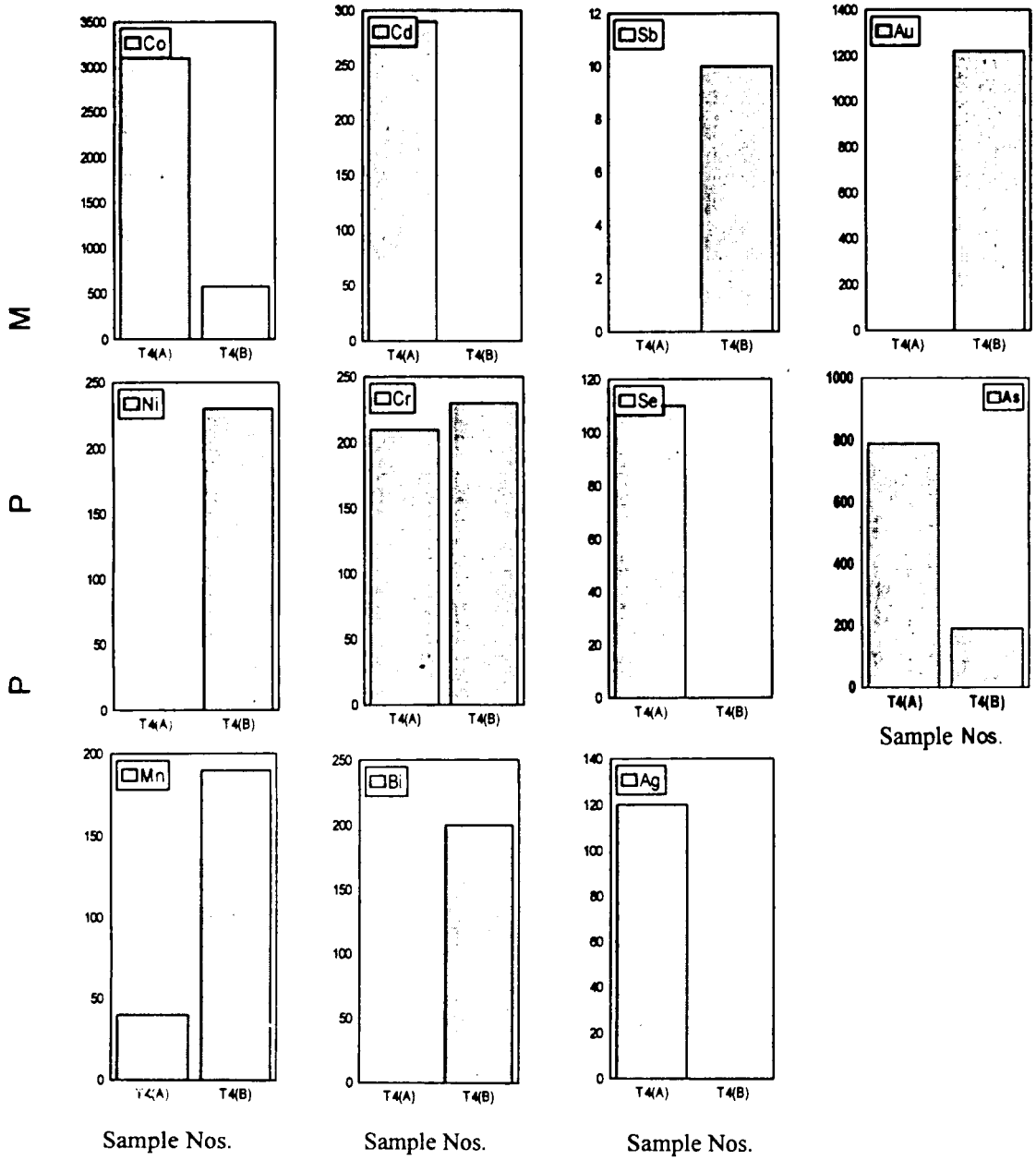


Fig. No.23

Histogram Showing Relative Abundance of Certain Elements in Sphalerite.
EPMA Data.
(In Ganeshpura Area)

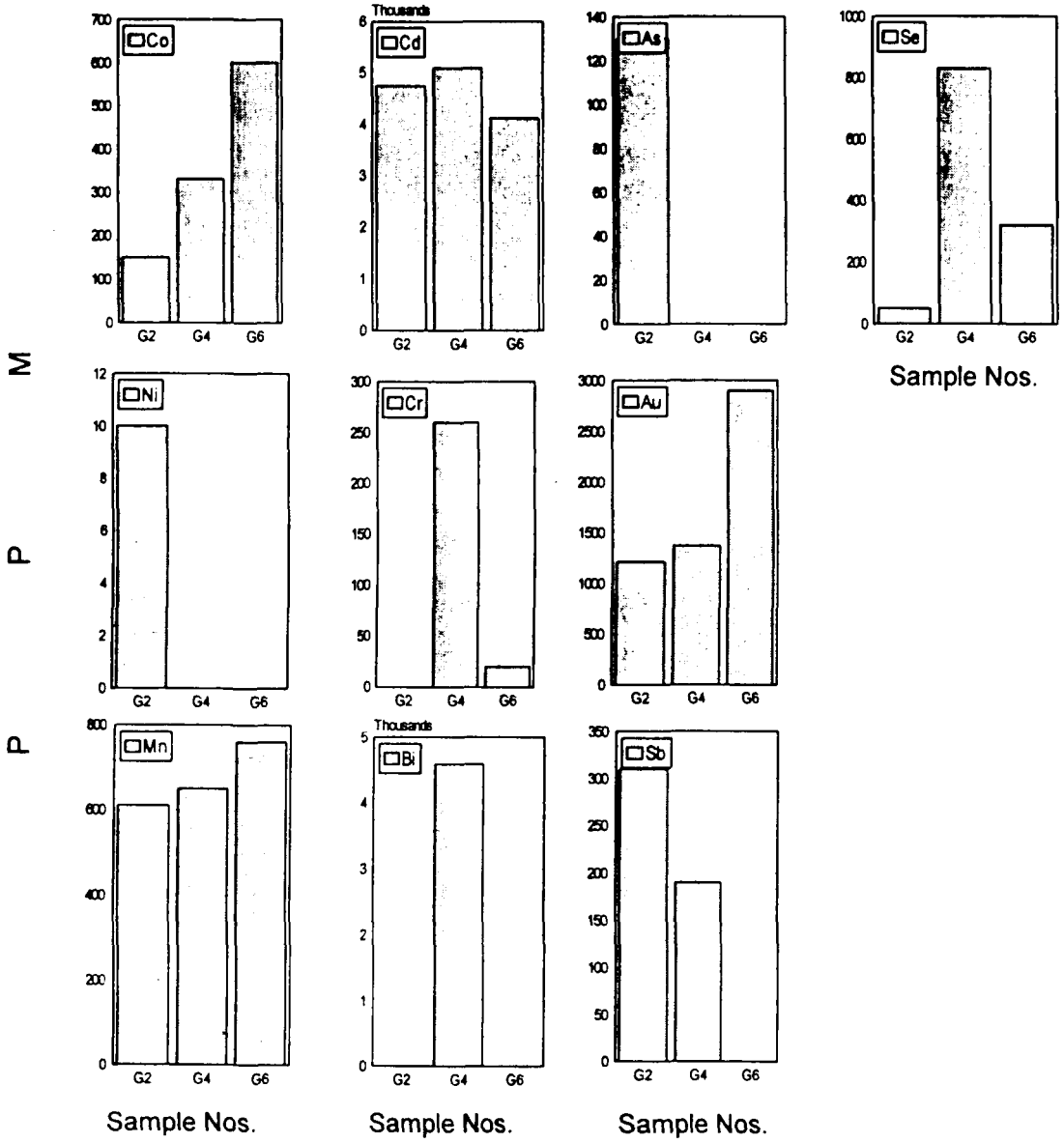


Fig.No.24

Histogram Showing Relative Abundance of Certain Elements in Galena ; EPMA Data.
(In Ganeshpura Area)

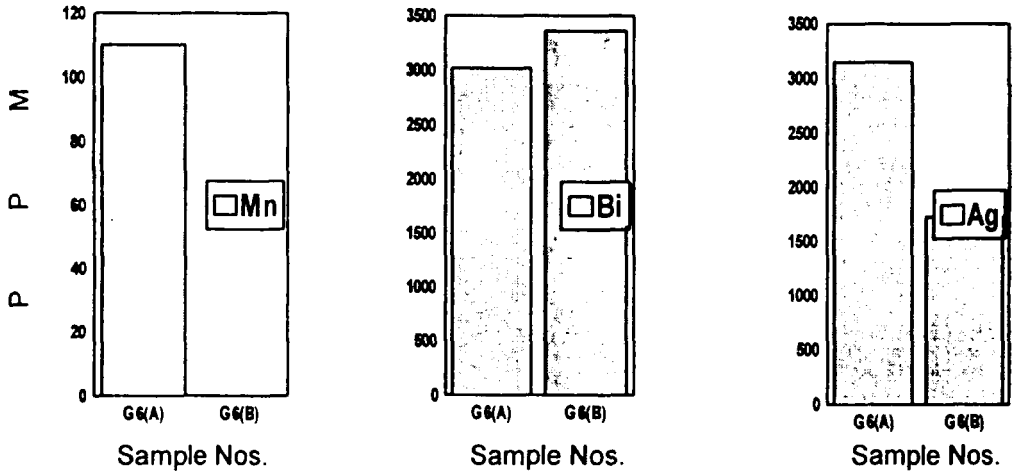


Fig.No.25

Pyrrhotite:

The average concentration of Co in pyrrhotite is 4850ppm and the average concentration of Ni in pyrrhotite is 210ppm. The lateral and vertical variation of Co, Ni and other metals in pyrrhotite is practically insignificant.

Pyrite:

The average concentration of cobalt in pyrite is 2714 ppm. The lateral and vertical variation of cobalt in pyrite does not show any significant variation. The average concentration of Ni in pyrite is 435 ppm., like Co,Ni in pyrite does not show any significance on lateral or vertical variation.

Evaluation:

Among Co,Ni,Mn,Cd,As,Bi,Cr,Ag,Au,Se and Sb the concentration of Co and Ni is in significant proportion in the pyrite, pyrrhotite and chalcopyrite, which may perhaps be used for the determination of the genetic type of the sulphide ore deposits. An attempt has been made to compare the average ratios of cobalt and Nickel with those of some well known genetic types of sulphide deposits of the world like those of magmatic, hydrothermal and sedimentary.

The average Co: Ni ratio in the chalcopyrite of the study area is 7.6 and the values are appreciably equal to those reported from the known hydrothermal ore deposits in which, the average ratio is greater than one, as reported by Hawley and Nichol, (1961).

Similarly, the average Co: Ni ratio in pyrrhotite of the study area is more than one. The average ratio in the pyrrhotite of hydrothermal origin are greater than one. (Thole, 1976)

The average Co:Ni ratio in pyrite of the study area is six. Usually, the average Co: Ni ratio in pyrite of sedimentary origin is limited to 0.63 (Bralia, et.al., 1979) and in those of hydrothermal origin, it ranges from 0.1 to 1.0 (Berg, and Friedensburg, 1944). The average Co: Ni ratio in pyrite of the study area is six, therefore, the pyrites may be regareted as hydrothermal.

Average Selenium (Se) in pyrite of the study area is 132ppm and average Sulphur in pyrite is 520551ppm i.e. the average S/Se ratio in pyrite of the study area is 3943. Goldschmidt (1954) suggested that selenium was concentrated in magmatic-hydrothermal ores, being rich in the high temperature deposits. Values in pyrite from such ores range from 0 to 1000ppm (Rosenfeld and Beath 1964, Faramazyan and Zaryah, 1964). In the study of Australian ores, Edwards and Carlos (1954) also found that pyrites of magmatic hydrothermal orgin generally has S:Se ratios of less

than 15,000, while those of sedimentary origin has ratios greater than 30,000.

Sphalerite:

The concentration of iron in sphalerite is found to be very high. It ranges from 4 weight percent to 11 weight percent. Cadmium is also high in concentration. The average concentration of cadmium in sphalerite is 4647ppm. The concentration of cobalt is very high in comparision with nickel. The concentration of gold and selenium is also marginal, the average being 1827ppm and 400ppm respectively.

Galena:

Galena of the study area contains 87% Pb and 13% Sulphur. The concentration of bismuth and silver is high in galena. The concentration of bismuth and silver in galena is 3190ppm and 2440ppm respectively.

CHAPTER - 7

SUMMARY
&
CONCLUSION

SUMMARY AND CONCLUSION

The purpose of the present investigation has been to investigate the nature of mineralisation of base metals in Sawar-Bajta area with particular reference to the geochemistry of the ores and the host rocks. Considerable attention has been given to study the petro-mineralogy of the host rocks and the mineralography of the sulphide ores. A summary of this investigation and conclusions drawn, are as follows.

1. The Sawar-Bajta area is considered as a part of the Bhilwara Supergroup and the metasediments are equivalent to Jahazpur, Pur-Banera and Rajpur-Dariba Groups.

The tectonic history of the area suggests that before the rocks attained their present status, three distinct deformational stages, having distinctive features of their own, effected the shear zone rocks to a great extent.

2. The structural pattern of the rocks are coaxial with the tectonic evolution of the area, mainly during the three successive deformational stages, resulting in the formation of various types of planar and linear structures and also the plunge inversion in the southern segment near Sawar. The general strike trend of the rocks of the area is from NNE to SSW whereas, at the fold closure the strike trend is in the East-West direction.

The sulphide ores are usually localised in the shear zones and also occur in the form of saddle reef pattern.

The present disposition of the ore bodies has largely been guided by the major structural trend of the shear zone and the ore localisations are intimately controlled by various minor structures of the host rocks.

3. The rocks, that compose the Sawar Group and fall within the study area, have been distinguished on the basis of their mineral assemblages, mineralogenic population and textural characteristics have been classified as follows.

1. Lower Marble
2. Lower Schist
3. Upper Marble
4. Upper Schist
5. Quartz vein and Silicified quartzite

In the Sawar Group, lower marble which is the host rock for the base matal mineralisation may be classified as impure marble and siliceous marble and they are composed of calcite, quartz, dolomite, muscovite, chlorite, biotite, sericite, diopside, tremolite, hornblende, periclase, epidote, apatite, feldspars, and forsterite.

In the host rock, calcite of two generation and quartz upto four generation have been identified. The quartz grains of four generations have been designated by quartz-I, quartz-II, quartz-III and quartz-IV.

The host rocks were subjected to alteration, the sequence of which has been determined as,

Silicification > Argillization >Sericitization.

The study of the mineral assemblages, textures and other petrographic characters of the rocks mentioned above, indicate that they have undergone progresive metamorphism varying from green schist to amphibolite facies.

4. The types of sulphide ores have been identified as disseminated type.

Mineragraphic study of the ores lead to the identification of number of ore minerals, which are as follows.

Major:-Galena, Sphalerite, Chalcopyrite, Pyrrhotite and Pyrite.

Minor:- Cubanite, Marcasite, Delafossite, Goethite, Cerussite and Cuprite.

The metamorphism of the ores is very prominent and it is evident through certain characteristic textural features such as replacement, annealing, exsolution and deformation. Replacement and annealing textures

are characteristics of dynamothermal and dynamic metamorphism whereas, the exsolution texture is indicative of falling temperature at retrogressive stage.

The presence of exsolved ore minerals and mineral assemblages suggest that the temperature at which they were formed, ranged between 250 to 550°C .

The paragenetic sequence of the ore minerals has also been determined on the basis of their mutual textural relations.

5. The geochemical abundance and variation range of the major oxides as well as some of the important trace elements in the host rocks of base metals have been critically studied with a view to trace the original nature of the rocks.

A close examination of the major oxides, viz; SiO2, Al2O3, CaO, MgO, Fe2O3, Na2O, K2O, MgO, MnO and P2O5 in the lower marble, collected from varying distances from the lode zone to the barren host rocks, indicates that the constituents have different trends of concentration with respect to the lode zone.

SiO2, CaO and MgO are showing decreasing trend towards the lode.

There is no appreciable change in the concentration of Al2O3, K2O, Na2O and MnO which have slightly increasing tendency towards the lode.

TiO2 decreasing towards the lode. P2O5 is slightly increasing towards the lode.

The concentration of Fe2O3 increases towards the lode.

6. Commonly, the host rocks and their sub-lithounits indicate alteration as a result of sericitisation, argillization and silicification.

It is difficult to identify the original chemical nature of the host rocks due to metamorphism and combined effects of various other alteration processes acting on them.

7. The trace elements such as Zn, Pb, Cu, Co, Ni, and Cr in the lower marble are quantitatively determined with a view to study their distribution trends in the above rocks and observed that copper, lead and zinc not only have higher average values but, a wide variation range in the lower marble. Generally, lead, zinc and copper show a tendency to increase in abundance in the host rocks as the ore bodies are approached.

Nickel and cobalt show a tendency to increase in their abundance towards the ore zone in the host rocks.

From the nature of the distribution of the trace elements, as stated above, no definite opinion regarding the geochemical relations among the rocks, under study, could be expressed.

8. In all twenty ore samples selected from the Sawar, Tikhi, Bajta and Ganeshpura areas were analysed for the quantitative determination of the concentration of Cu, Zn, Pb, Ni, Co, Cd, As, Cr, and Bi and also to determine the percentage of oxides viz; SiO2, TiO2, Al2O3, Fe2O3, MnO, CaO, MgO, Na2O, K2O, P2O5 and the loss on ignition(LOI). In most of the ore samples of the study area, cobalt is invariably dominant over nickel.

Cu, Fe, Zn, S, Pb, Cd, Co, Ni, Mn, As, Sb, Bi, Se, Ag, Au, and Cr in chalcopyrite, pyrite, pyrrhotite, sphalerite and galena of the Sawar-Bajta area have been studied in an attempt to trace their distribution trends in the ore deposits.

The average Co:Ni ratios in the chalcopyrite of the study area is 7.6 and the value is appreciably equal to those reported from the known hydrothermal deposits in which the average ratio is greater than one, as reported by Hawley and Nichol (1961).

The average Co:Ni ratio in pyrrhotite of the study area is more than one, similarly, the average Co:Ni ratio in the pyrrhotite of hydrothermal origin is greater than one (Thole, 1976).

Co:Ni ratio in pyrites of the study area with a range of their average being 3.2 to 5.8. Higher Co:Ni ratios in hydrothermal pyrites than in pyrites from ultrabasics are indicated by Hawley and and Nichol (1961), and data by Berg and Friedensburg (1944) indicate that in hydrothermal sulphides the Co:Ni ratio is often greater than one and in hydrothermal pyrite may be as high as 830, and the average Co:Ni ratio in pyrite of sedimentary origin is limited to 0.63 (Bralia et.al., 1979).

On the basis of average Co, Ni ratio in chalcopyrite, pyrrhotite and pyrite, the sulphide ores of the study area have been compared with those of known genetic type particularly hydrothermal deposits. The pyrrhotite associated with the ores of Sawar Group are similar to those found in the same ore minerals of hydrothermal origin, on the other hand, the average Co:Ni ratios in pyrite of the study area are appreciably equal to those recorded from pyrites of hydrothermal deposits . Accordingly, it is obvious that sulphide ores having chalcopyrite, pyrrhotite, sphalerite, galena and pyrite of the study area could be regarded as the hydrothermal deposits.

Ray (1988) worked in the Sawar-Bajta area and concluded that the metasediments of the high grade terrain were the source rocks for the

mineralising fluids, from which the metals were removed in the form of superheated brines during the course of regional metamorphism and carried to the structural traps in the lower marble of the area under investigation (Sawar-Bajta area of Ajmer district, Rajasthan).

REFERENCES

REFERENCES

Anon, 1981. Explanatory brochure to the geological map of the Aravalli region in southern Rajasthan and northeastern Gujarat, Geol. Surv. of India publication, P.1-38.

Banerjee, A.K., and Mitra, S.K., 1977. Deformation and metamorphism in the Precambrians of Rajasthan Jour.Geol.Soc. India., vol.18, P.644-652.

Barton, P.B., and P. Toulmin, III., 1966. Phase relations involving sphalerite in the Fe-Zn-S system.Econ.Geol.61, P.815-849.

Berg, G. and Friedensburg, F., 1944. Nickel und kobalt. Diemetallischen Rohistoffe, ihre hagerungs verhaltnisse Und ihre wirtschoftliche Bedeuting, stuttgard. Enke, 280p.

Bhola, A.M., and Varadarajan, S., 1981. Polyphase deformation of Ajabgarh stage rocks, Delhi around Narnaul, Mohindergarh district, Haryana,India. Jour.Geol. Soc.India. Vol.22, P. 153-163.

Bhola, A.M.,and Saberwal, K.K.,1982. Deformation structures in the Delhi group of rocks around Nibhor, Rajasthan. Jour. Geol. Soc. India. Vol.23, P.521-538.

Bhola, K.L. 1935; Contribution to discussion on Dr.A.M. Heron's paper "The mineral resources of Rajasthan". Trans. Min. Geol. Inst., vol.29, part-IV.

Bralia, A., Sabatini, G. and Troja, F., 1979. A revaluation of the Co:Ni ratio in Pyrite as geochemical tool in ore genesis problems. Evidences from South

Tuscany pyrite deposits. Mineralium Deposita, Vol.14, P.353-374.

Buerger, N.W., and Buerger, M.J., 1934. Crystallographic relations between cubanite segregation plates, Chal copyrite matrix and secondary chalcopyrite twins. Amer. Mineralogist, Vol.19, P.289-303.

Burns, R.G., and Fyfe, W.S., 1967. Trace element distribution rules and their significance Chem. Geol., Vol.2, P.89-104.

Carstens, C.W., 1931. Die kicsvorkommens in Porsangergebiet, Norsk Geol. Tidsskr, Vol.12, P.171-177.

Chaudhry,A.K., Geopalan, K., and Sastry, C.A., 1984. Present status of the Geochronology of the Precambrian rocks of Rajasthan. Tectonophysics, Vol.105,P.131-140.

Clark, B.R., Price, F.R., and Kelly , W.C., 1977. Effects of annealing on deformation textures in galena. Contributions to Mineralogy and Petrology. Vol.64, P.149-165.

Crawford, A.R., 1970. The Precambrian Geochronology of Rajasthan and Bundelkhand, northern India. Can. J. Earth Sci., Vol.7, P.91-110.

Crookshank, H., 1948. Minerals of the Rajputana pegmatites. Mining, Geol., Metall. Inst. India Trans., V.42, P.105-189.

Deb, M., and Bhattacharya, A.K., 1980. Geological setting and conditions of metamor phism of Rajpur-Dariba polymetallic deposits, Rajasthan, India. Proc. Fifth IAGOD symposium snowbird. U.S.A. Scheez verlogsbuch handlang, stutgard, PP.679-697.

Deb, M., and Sarkar, S.C., 1990. Proterozoic tectonic evolution and metallogenesis in the Aravalli-Delhi orogenic complex, NW India, Precambrian Res. Vol.46, P.115-137.

Deb M., Thorpe, R., Cumming, G.L. and Wagner, P.A., 1989. Age source and stratigraphic implications of Pb isotope data for conformable, sediment hosted, basemetal deposits in the pral.Arav. Delhi Orog.belt, NW India Precambrian Research, Vol.43, P.1-22.

Domarev, V.C., 1956. Nekotorye geoligischeskie Osobennostifo metamorfogennykh rundnykh mestovozhdenni (some geological features of metamorphic ore deposits) Usesoynz Nauchn. Issled. Geol. Inst. Materialy (Geol.Polezn. Isokop), 8, P.7-41.

Edwards, A.B., and Carlos, G.C., 1954. The content of some Australian sulphide deposits. Proc. Australasian Inst. Mining Met., 172, P.31-63.

Erkama, J., 1947. Uber die Rolle von kupfer Und Mangan in Leben der hoheren pflanzen. Ann. Acad. Sci. Fennicae, Ser. A, II, 25.

Farmazyan, A.S., and Zaryon, R.N., 1964. Geochemistry of selenium and tellurium in the ores of the kodzhuran deposit. Geochem. Intern. 1, P.1103-1105.

Friedman, G.M., 1959. The Samried lake sulphide deposit, Ontario, an example of pyrrhotite-pyrite iron formation. Econ. Geol., Vol.54, P.268-284.

Gammon, J.B., 1966. Fahlbands in the Precambrian of South ern Norway. Econ. Geol., Vol.61, P.179-188.

Goldsmidt.V.M.,1937. The pinciples of distribution of chemical elements in minerals and rocks. J.Chem. Society, Pt.1 PP. 655-673.

Goldschnidt, V.M., 1954. Geochemistry. Oxford University Press, London. 730 P.

Goodwin, A.M., 1991. Precambrian Geology. Academic Press. 666 P.

Gopalan, K., Trivedi, J.R., Balasabrahmanyam, M.N., Ray, S.K., and Sastry, C.A., 1979 a. Rb-Sr. Chronology of Khetri copper belt, Rajasthan. Geol. Soc. of India J., Vol.20, P.450-456.

G.S.I., 1977. Geology and mineral resources of the states of India. Part XII, Rajasthan. Geol. Sur. of India Misc. pub., Vol.30, 75P.

Graf.J.L., Jr. and Skinner, B.J., 1970. Strength and deformation of pyrite and pyrrhotite. Econ. Geol., Vol.65, P206-215.

Gupta, S.N., Arora, Y.K., Mathur, R.K., Iqbaluddin, Sahni, T.N., and Sharma, S.B., 1980. Lithostratigraphic map of Aravalli region, southern Rajasthan and north eastern Gujarat. Geol. Sur. of India, Calcutta.

Harrison, J.M., 1950. Possible major structural control of ore deposits in Flin Flon-Show Loke mineral belt. Monitoba, can. Inst. Min. Metall, Bull., Vol.44, PP.4-8.

Hawley, J.E., and Nichol, I., 1961. Trace elements in Pyrite Pyrrhotite and chalcopyrite of different Ores. Econ. Geol., Vol.56, P.467-487.

Heron, A.M., 1953. The Geology of central Rajputana. Memoirs Geol. Surv. India, Vol.79 (1), 389 P.

Hevesy, G., Habbie, R., and Holmes, A., 1931. Lead contents of rocks.Nature, Vol. 128, PP.1038.

Iqbaluddin, 1989. Geology of the kodana reservoir area. Panchmahal district, Gujrat and Banswara and Dangarpur district, Rajasthan. Mem. Geol. Survey of India, Vol.121, P.1-84.

Jain and Devapriyan, 1967. Rec. Geol. Surv. of India, Vol.99, Part.-I, Annual general report of the year 1964-65 .

Jain and Devapriyan, 1972. Rec. Geol. Surv. of India, Vol.102, Pt.1. Annual general report of the year 1966-67.

Jain and Devapriyan, 1972. Rec. Geol. Surv. of India, Vol.102, Pt.I, Annual general report of 1967-68.

Jain and Devapriyan, 1972. Rec. Geol. Surv. of India, Vol.103, Pt.1, Annual general report of 1968-69.

Jain and Devapriyan, 1974. Rec. Geol. Surv. of India, Vol.104, Pt.1, Annual general report of 1969-70.

Jain and Devapriyan, 1975. Rec. Geol. Surv. of India, Vol.105, Pt.1, An nual general report of 1970-71.

Kanehira, K., 1959. Geology and ore deposits of the Chihara mine, Ehime prefecture, Japan, Tokyo Univ. Fac. Sec. Jour., Sec. 2, Vol. 11, P,309-388.

Loftus-Hills and Solomon, M.,1967. Cobalt, Nickel and Selenium as idicators of ore genesis, Mineralium Deposita, Vol.2, P.228-242.

Lowell, J.D., and Gilbert, J.M., 1970. Lateral and vertical alteration mineralisation zoning in porphyry ore deposits. Econ. Geol., Vol.65, P.373-408.

Lundegardh, P.H., 1947. Some aspects to the determination and distribution of zinc. Ann. Roy. Agr. Coll. Sweden 15.

Mason, B., 1958. Principles of geochemistry, 3rd ed. John Wiley and Sons, Inc., New York, 329 P.

Mc Donald, J.A., 1967. Metamorphism and its effects on sulphide assemblages. Mineralium Deposita, Vol.2, P.200-220.

Mc Dougall, J.D., Gopalan, K., Lugmair, G.W., and Roy, A.B., 1983. An ancient de pleted source for Archaean crust in Rajasthan, India. (Abs.) In : workshop on a cross section of Archaean crust. Lunar planer Inst. Houston Tech. Rep. 83-03 :P. 55-56.

Meyer, C., and Hemly, J.J., 1967. Wall rock alteration. In. Barnes, H.L. (Ed.), Geochemistry of hydrothermal ore deposits, Holt, Rinchert and Win ston, Inc., New York, P.166-235.

Mookherjee, A., 1971. Deformation of pyrite. (Discussion of the paper by Graf and Skinner). Econ. Geol., Vol.66, P.200.

Mookherjee, A., 1976. Ores and metamorphism. Temporal and genetic relationships. Wolf K.H. (Ed.), In. Hand book of stratabound and stratiform ore deposits. Elsevier Sci. Publ. Co., Amsterdam, 4. P.203-260.

Mukhopadhyay, D., and Dasgupta, S., 1978. Delhi-Pre Delhi relations near Bandor, Central Rajasthan. Indian Jour. Earth Sci., Vol.7, P.64-75.

Naha, K., and Chaudhry, A.K., 1968. Large scale fold interference in a metamorphic migmatitic complex. Tectonophysics, Vol.6 (2) P.127-142.

Naha, K., and Majumdar, 1971 b. Reubteroretation of the Aravalli basal conglomerate at Morchana, Udaipur district, Rajasthan, western India. Geol. Mag., Vol.108, P.111-114.

Naha, K., and Halyburton R.V.,1974. Early precambrian stratigrophy of central southern Rajasthan, India. Precambrian Research, Vol.1, 53-73.

Naha, K., and Halyburton, R.V., 1974b. Late stress system deducted from conjugate folds and kink bands in the "Main Raialo syncline" Udaipur dist. Rajasthan, India. Geol. Sci. Am. Bull., Vol.85, P.251-256.

Naha, K., and Roy, A.B., 1983. The problem of the Precam-brian basement in Rajasthan, western India., Precambrian Research, Vol.19, P.217-223.

Naha, K., Mukhopadhyay, D.K., Mohanty, R., Mitra, S.K., and Biswal, T.K., 1984. Significance of contrast in the early stages of the structural history of the Delhi and pre Delhi rock groups in the proterozoic of Rajasthan, western India. tectonophysics, Vol.105, P.193-206.

Naqvi, S.M., and Rogers, J.J.W., 1987. Precambrian Geology of India, Clarendron Press, New York.

Newhouse, W.H., 1936. Opaque Oxides and sulphides in common igneous rocks. Bull. Geol. Soc. Am., Vol.47, P.1.

Page, N.J., 1963. The sulphide deposit of Nords Gejtryggen, Folldal, Norway. Norges. Geol. Undersokelse, No.228, P.217-269.

Paliwal, B.S., 1988. Deformation pattern in the rocks of the Aravalli Supergroup around Udaipur city, Rajasthan. Precambrian of the Aravalli Mountain, Rajasthan, India. Geol. Soc. of India, No.7, P.153-168.

Pandya, M.K., 1981. Petromineralogy and petrochemistry of the rocks of Hammer head syncline of Kankroli, Udaipur district, Rajasthan-A case of high grade regional metamorphism in Aravalli (Abstract). In symposium on three decades of development in petrology, min eralogy and petrology in India. Geol. Surv. of India, Jaipur, P.90.

Pascoe E.H., 1926. General report for the year 1924. Rec. Geol. Surv. India, V.58.

Pascoe, E.H., 1965. A manual of Geology of India and Burma, Vol.1, 485 P.

Poddar, B.C., 1966. An example of contrasted tectonic regimes from Precambrians of Udaipur dist., Rajasthan, Indian minerals, Vol.20, P.192-194.

Powar,K.B., and Patwardhan, A.M., 1984. Tectonic evolution and base metal mineralisation in the Aravalli-Delhi Belt, India, Precambrian Research. Vol.25, P.309-323.

Raja Roy, C.S., Poddar, B.C., Basu, K.K., and Dutta, A.K., 1971. Precambrian stratigraphy of Rajasthan. A review Geol. Survey of India Records, Vol. 101, Part 2, P.60-79.

Raja Rao, C.S.,1976. Precambrian sequences of Rajasthan, Geol. Surv. of India, Misc. Publ., Vol.23, Part 2, P.497-516.

Ramdohr, P., 1940. Die Erzmineralien in gewohnlechen magmatischen Gesteinen. Abhandl. Preuss. Akod. Wiss, Math-natutw. Klasse, No.2.

Ramdohr, P., 1953 a. Upper metamorphose and sekundase mobilisierung, Geol. Rundschu, Vol.42, P.11-19.

Ramdohr, P., 1969. Ore minerals and their intergrowth. English translation. 3rd Pergaamon, Oxford,P.1174.

Rankama, K., and Sahama, T.G., 1950. Geochemistry. The University of Chicago press.

Ray, S.K., 1974. Inversion of fold hinges in superposed folding. An example from the Precambrian of central Rajasthan. Precambrian Res., Vol.1, P.157-164.

Ray, S.K., 1986. Stractural control of copper mineralisation in the Sawar group of rocks, Ajmer district, Rajasthan. Seminar. Evol. of the precambrian Crust in the Aravalli mountain belt. Udaipur, (Abst.), 46 P.

Ray, S.K., 1988. Structural control of copper mineralisation near Bajta, Ajmer district, Rajasthan. Precambrian of the Aravalli Mountain, Rajasthan, India,

Memoir 7, Geol. surv. of India, P. 363-372.

Roday, P.P., 1979. Structural pattern in the Ajabgarh rocks around Anakhor, district Ajmer, Jour. Geol. Soc. India, Vol.20, P.441-449.

Rose, A.W., 1970. Zonal ralations of wall rock alteration and sulphide distribution at porphyry copper deposits. Econ. Geol., Vol.65, P. 920-936.

Roy, A.B., 1973. Nature and evolution of subhorizontal crenulation cleavage in the type Aravalli rocks around udaipur, Rajasthan. Proc. Nat. Inst. Sci. India, Vol. 39, P.

Roy, A.B., Nagori, D.K., Golani, P.R., Dhakar, S.P., and Chaudhry, R., 1980. Structural geometry of the rocks phosphorite bearing Aravalli rocks around Jhamarkotra mines area, Udaipur district, Rajasthan. Indian Jour. Earth Sci. Vol.7 (2), P. 191-202.

Roy, A.B.,and Paliwal, B.S., 1981. Evolution of lower proterozoic epicontinental deposits, Stromatolite bearing Aravalli rocks of Udaipur, Rajasthan, India. Precamb. Res. Vol.14, P. 49-74.

Roy, A.B., 1985. Tectonic and Stratigraphic framework of the Early Precambrian rocks of Rajasthan and Northern Gujarat. Bull. Geol. Met. Soc. India. Vol. 53, P.100-114.

Roy, A.B., and Das, A.R., 1985. A study of time relations between movements, meta morphism and granite emplacement in the middle Proterozoic Delhi Supergroup of Rajasthan. Jour. Geol. Soc. India, Vol. 26, P.726-733.

Roy, A.B., 1988. Stratigraphic and tectonic framework of the Aravalli mountain Range. Precambrian of Aravalli mountain, Rajasthan, India. Geol. Soc. of India, No. 7, P. 3-31.

Salmon, B.C., Clark, B.R., Kelly, N.C., 1974. Sulfide deformation studies :II. Experimental deformation of galena to 2000 bars and 4000°C, Econ. Geol. vol.69, P.1-16.

Sandell, E.B., and Goldich, S.S., 1943. The rarer metallic constituents of American igneous rocks. I.J. Geol., Vol.51, PP. 99., II Ibud., P. 167.

Sastry, C.A., Gopalan, K., and Chaudhory, A.K., 1984. Proposal for the classification of the precambrian rocks and events from Rajasthan and NE Gujrat (Abstract). Proc. seminar on crustal evolution of the Indian shield and its bearing on metallogeny, 12-14 January, 1988, Dept. of Geol., Presidency college, Calcutta, 11-12.

Sen, S., 1983. Stratigraphy of the crystalline Precambrian of central and northern Rajasthan., A review. In : S.Sinha Roy (Ed.) Structure and tectonics of the Precamb. rocks. Recent Researchers in Geology, Vol.10, Hind. Publ. Corpn., Delhi, P. 26-39.

Sharma, R.P., 1983. Structure and tectonics of the Bundelkhand complex, central India. Recent Res. Geol. Vol.10, P. 198-210.

Sharma, R.S., and Narayana, V., 1975 a. Distribution of elements between Coexisting garnet biotite and muscovite biotite pairs from polymetamorphic schists of southeast Beawar, Rajasthan, India. Schweiz. Mineral. Petrog. Mitteilungeh, Vol.55, P. 61-77.

Sharma, R.S., and Narayana, V., 1975 b. Petrology of polymetamorphic schists from an Archaean complex terrain, southeast of Beawar, Rajasthan, India. Neues Jahrb. Mineral. Abh., Vol.124, P.190-222.

Sharma, R.S., and Narayana, V., 1975c. Wallastonite paragenesis in a regional metamorphic terrain southeast of Beawar, Rajasthan, India, Neues Jahrb. Mineral. Monatsh., No. 12, P. 561-569.

Sharma, R.S., and Ray, A.K., 1979. On the polymineralic paragenesis from karera, District Bhilwara, Rajasthan I. Petrography and mineralogy. Ind. Jour. Earth Sci. Vol.6, P. 67-81.

Sharma, R.S., and Ray, A.K., 1980. On the Polymineralic paratneisses from karera, Dist. Bhilwara, Rajasthan II. Phase relations and paragenesis. Ind. J. Earth Sci., Vol.7, P. 131-145.

Sharma, R.S., 1982.Mineralogy of scapolite bearing rock from Rajasthan, north west Peninsular India. Lithos, Vol.14, P. 165-171.

Singh, S.P., 1988. Stratigraphy and sedimentation pattern in the Proterozoic Delhi Supergroup, NW India, Geol. Soc. India, Mem. 7, P. 193-205.

Sivaraman, T.V., and Odom, A.L., 1982. Zirchon geochronology of Berach granite of Chittorgarh, Rajasthan. Geol. Soc. India J., Vol.23, P. 575-577.

Stanton, R.L., and Gorman, H., 1968. A phenomenological study of grain boundary migration in some common sulphides. Ecom. Geol. Vol.63, P. 907-923.

Stanton, R.L., 1972. Ore petrology. Mc. Graw Hill Book company Inc., New York, 713 P.

Straczek, J.A., and Srikantan, B., 1966. Geology of Zawar lead-zinc deposits. Mem. Geol. Surv. India Vol. 92, P. 1-85.

Thole, R.H., 1976. The geology of shamrocke mine, Rhodesia - a stratiform copper deposit. Econ. Geol., Vol.71, P. 202-228.

Touson, L.V., 1965. Factors in the distribution of trace elements during crystallization of magma. Rhys.Chem. Earth, Vol.6., P. 215-278.

Vogt, T., 1942. Geokjemisk of geobotanisk malmleting Viscaria alpina (L.) G. Don som "kisplante". Kgl. Norske videnskab. Selskbs Forh. 15, No.2, P. 5.

Vokes, F.M., 1963. Geological studies on the caledonian Pyrite-Zinc-lead ore body at Bleck vassle Nordland, Norway. Norges geol. Undersokelse, 222, P. 1-126.

Vokes, F.M., 1969. A review of the metamorphism of sulphide deposits. Earth Sci. Rev., Vol.5, P. 99-143.

Yund, R.A., and kullerud, G., 1966. Thermal stability of assemblages in the Cu-Fe-S System. Jour. Petrology, Vol.7, P. 457-488.

Zavaritsky, A.N., 1950. Metasomatism and metamorphism in the pyrite deposits of the Urals. 18th Int. Geol. Congress, London, 1948, Rept. 3(B), P. 192- 208.